

REPORT TO THE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ON
RUBIDIUM⁸⁷ GAS CELL STUDIES

(PHASE II)

NGR 52-133-001

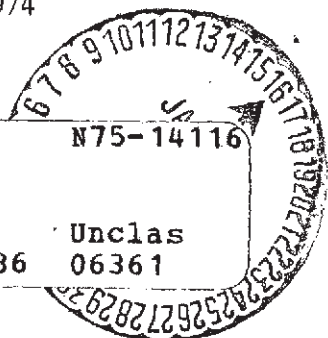
Period covered: August 1, 1972 to January 30, 1974

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February 1974

FOREWORD

This report is concerned with the construction of a compact Rb^{87} maser, of its control electronics and of a receiver capable of locking a crystal oscillator to the maser signal.

The project was realized with the help of a grant from the National Aeronautics and Space Administration (NGR-52-133-001). It is the second phase of a development program on Rubidium masers. The work was done in the Quantum Electronics Laboratory of the Electrical Engineering department of Laval University. The research of this laboratory is oriented mostly towards the study of atomic frequency standards and extends to many aspects of studies on standards that can be derived from Quantum Electronics phenomena. This project is part of this general program.

Jacques VANIER
Professor
(Principal investigator)

INTRODUCTION

Rubidium masers are well known for their unsurpassed short term stability. Previous measurements have shown this characteristics and results have been published elsewhere (1). These results were obtained on rather crude laboratory type masers and their design had a lot to be improved on. In fact the masers were large and bulky. This was due to two factors. First much of the design specially on the magnetic shielding was borrowed directly from hydrogen maser technology. Secondly the masers were built for easy access in order to rapidly change components. Furthermore, in those masers, the output appeared as a signal at 6.834 GHz and a receiver capable of locking a crystal oscillator at 5 MHz to the maser signal was highly desirable. This report gives details of the construction of a compact rubidium 87 maser. It is of the same type, "quartz cavity - quartz bulb", as the early models built in our laboratory but is of a much smaller size. However its design is much improved upon the earlier ones. This report gives also the design of a receiver capable of locking a crystal oscillator to the maser signal.

For convenience we have divided this report into 4 sections which deals respectively with 1) the maser construction, 2) the maser control electronics, 3) the receiver, 4) some preliminary experimental results on the maser characteristics.

1) The Rb^{87} maser

Figure 1.a shows the details of the compact Rb^{87} maser that was built. One of the essential part of the maser is a main aluminum cylinder which serves two purposes: a) it serves as a support of the various components and b) it plays an important role in maintaining the cavity at a constant temperature with negligible gradients.

The quartz cylinder forming the body of the cavity is silver plated on its inside and is held tight inside the aluminum cylinder by silicone rubber O rings. This cylinder sits on a bottom plate which is attached to the main cylinder and which is in good thermal contact with it. The top plunger of the cavity, used for coarse tuning, is highly transparent to the pumping light. It is made of a copper disk 1 cm thick drilled with small holes acting as cut off wave guides at the microwave frequency at which the cavity resonates (~ 6835 MHz). This top plunger takes its reference point on the quartz cylinder itself. It is held in place by beryllium copper springs which themselves are held by a ring attached to the main aluminum cylinder. The arrangement provides a certain amount of compensation against temperature fluctuations. Actually the temperature coefficient of the cavity is approximately $2.7 \text{ KHz}/^\circ\text{C}$ and depends on the storage bulb used.

The maser storage bulb, used in this type of design, (in contrast to the stainless steel vacuum tight design) is made of high quality used silica and fills almost entirely the inside of the cavity. This is done in order to make the filling

factor as large as possible. The construction of the bulb is also characterized by very thin walls. This is done in order to minimize dielectric loading and associated microwave losses which would decrease the quality factor of the cavity (2). The bulb has a single tail which is used as the rubidium reservoir. The bulb is filled with 10 Torr of N_2 for maximum gain (3,4) and a few mg of Rb. The filter cell is attached to the main cylinder through an aluminum O ring. This cell is made of pyrex and its dimensions are 3" in diameter and $1\frac{1}{2}$ " in length. It is filled with 70 Torr of Argon and a few milligrams of Rb^{85} .

An initial design of the lamp which consisted of seven small independent units, has been discarded. The main reason was the dissipation of heat inside the maser by the lamp oscillator driving transistors. It was very difficult to control the maser temperature since most of the heat was coming from these transistors. The final design retained is that using a single 1" bulb inside a 3" polished aluminum reflector. The lamp is driven by an external oscillator to the maser. In this way heat dissipation problems in the maser are avoided and the power to the lamp can be controlled easily. The whole arrangement, cavity filter and lamp, is surrounded by three concentric magnetic shields. A solenoid creating the magnetic field of the maser is placed inside the magnetic shields. It incorporates one compensating coil for a first order correction to the inhomogeneity of the main solenoid field. The temperature of the maser is maintained constant through five temperature controls driving heaters situated in five critical regions. These heaters are distributed as follows: 1) one outer oven between the innermost

shield and the second one 2) one inner heater wound directly on the main aluminum cylinder 3) one heater for controlling the temperature of the rubidium reservoir or bulb tail 4) one heater for the filter cell 5) one heater for the lamp. All these temperatures are regulated.

The maser as such is mounted in the back of a 19" wide standard rack panel, mounted itself on a cart that can be transported with the control electronics and the receiver.

The drawings of all the parts of the maser are included in annex (A). Figs. 1-b,c show the physical appearance of these parts while Fig. 1-d shows the maser in its movable cart. Fig. 1-e shows the complete unit including the receiver and control electronics.

2) Maser control electronics

The maser control electronics consists of three main units 1) the temperature controls 2) the lamp oscillator 3) the magnetic field control.

The temperature controls

The five temperature controls are of identical construction. The circuit used is given on figure 2. The sensors of each unit is a thermistor which is mounted in a Wheatstone bridge. The temperature is set by adjusting the value of resistor R_X . The differential amplifier A_X senses the unbalance of the Wheatstone bridge and commands a power transistor to supply more or less current to the heater wires.

The heaters themselves are made of bifilar twisted resistance wire. This technique is relatively simple to use and is extremely efficient in avoiding the creation of stray magnetic fields.

These kind of control have a wide range of operation and gives temperature stabilities of the order of 0.01°C . depending on the isolation, for external variations of the order of 5°C . They are used throughout the system for controlling the temperature of various regions.

We have tried to keep the various control points as independent as possible, but this cannot be done completely. Consequently the temperature of the various elements of the maser is dependent somewhat on the setting of the temperature of the other elements. In fact one wants in the same unit the four settings.

Cavity and maser bulbs :	$T_C \approx 60^{\circ}\text{C}$
Rubidium reservoir :	$T_R = T_C - (2^{\circ}\text{C to } 5^{\circ}\text{C})$
Filter cell :	$T_C \approx 75^{\circ}\text{C to } 80^{\circ}\text{C}$
Lamp :	$T_L \approx 115^{\circ}\text{C}$

The gradient between the maser bulb and the rubidium reservoir is necessary in order to keep to a minimum value, the microwave losses which would be created in the cavity by a rubidium film.

The lamp oscillator

The lamp is driven by an oscillator external to the maser cohue circuit is shown in figure 3. The coupling to the lamp is made through a loop at the oscillator end. At the lamp bulb the discharge is excited by a coil mounted around the lamp itself and tuned to the frequency of the oscillator through capacitor C_T . The match to the transmission line is obtained by feeding this parallel resonant circuit through the transformer formed by the coil itself. In fact the transmission line is connected at approximately 1 turn from one end of the coil which is made of seven turns. This method of coupling permits the realisation of an almost perfect match. The power to the lamp itself can be varied by varying the voltage applied to the oscillator. Due to the thermal isolation that exists around the lamp, approximately 5 watts of r.f. are enough to drive the lamp and bring it to approximately 115°C as required. However this is an undesirable state of operation because the temperature of the lamp is controlled by the oscillator power. It is then preferable to operate the lamp with a somewhat lower power and to compensate by heating it through an external thermal control. This method allows a more stable state of operation by controlling the temperature of the lamp. The r.f. power to the lamp, however, is left uncontrolled but this is quite standard practice in rubidium passive clock technology where good results are obtained. Effectively, it is found in general that the maser frequency through the light shift depends more on the lamp temperature than on the r.f. power itself if the lamp temperature is controlled mainly from an external oven. Furthermore it was found in the maser built, that the lamp temperature being quite high (115°C) had a direct influence on

the maser bulb and cavity temperature and produced frequency fluctuations in the maser output. These were caused through the combined effect of the buffer gas temperature coefficient and the cavity pulling. This was another reason why the temperature of the lamp was regulated.

The magnetic field control

The magnetic field is created by a solenoid driven by a current source. The diagram of this source is given in figure 4. The circuit is designed in such a way as to control both the main solenoid and the first order correction coil at the same time, once the ratio of the current of both coils has been established for proper operation.

3) The receiver

The block diagram of the complete receiver is shown on figure 5. It consists essentially of a basic crystal oscillator with 10 MHz output frequency. This frequency is multiplied by 680 giving an output at 6.8 GHz. This frequency is mixed with the maser signal in a balanced mixer (and the signal at the difference frequency (34.6 MHz) is amplified through amplifier A_6). This amplified signal is again mixed with a signal at 30 MHz derived by multiplication ($\times 3$) from the basic crystal oscillator. The difference frequency of the order of 4.68 MHz is amplified and mixed again with a 5 MHz signal obtained by division ($\div 2$) from the main basic oscillator. The am-

plified difference frequency at 311 ... KHz is amplified and mixed with a signal at 300 KHz obtained through multiplication of the basic oscillator by $\frac{3}{100}$. The difference frequency 11 ... KHz is then compared in phase with the output of a synthesizer driven by the basic crystal oscillator. The synthesizer is operated at 11 ... MHz and then divided by 1000 to obtain fine adjustment on the frequency from a coarse variation on the synthesizer itself. This technique has also the advantage of reducing somewhat the noise. The phase difference between the two signals at the level of 11 KHz appears at the output of the phase detector as a d.c. signal which is used as an error signal through an integrator to correct the basic crystal oscillator from any deviation in phase relative to the maser signal. This is a phase lock loop system and the crystal oscillator is locked in phase to the maser signal.

Most of the items shown on figure 5 have been designed and constructed in our laboratory. The units that have been obtained commercially are:

Isolator I_1
 Attenuator At_1
 Multiplier Mu_5
 Mixer Preamp. $M:A_1$
 Synthesizer (11.5 MHz)
 Master Oscillator VCXO

The circuits diagrams of all the other units in figure 5 are given in annex B.

4) Preliminary results on the system characteristics

Although the system performance has not been studied in detail yet, the characteristic of the maser as such has been investigated relative to its frequency stability. These measurements were made in two steps.

- a) The maser was compared directly with one of our laboratory model maser through the arrangements shown a figure 6. This technique permits measurements in the range of integration times from approximately 1 msec to 1 sec.
- b) For times longer than 1 sec the stability of the Rb maser used as reference is not good enough and one has to use a different set up. This is shown in figure 7. In this case a hydrogen maser serves as the reference. A crystal oscillator phase locked to the hydrogen maser was used to drive a synthesizer which was then multiplied to a frequency of 6834 MHz. This was then used as the reference oscillator and measurements could be done in a standard way. The results obtained are shown in figure 8.

DISCUSSION OF THE RESULTS

The results reported here are very promising. In fact the medium term stability of the maser is rather good. This was obtained

simply by using known technology and improving the mechanical design of early models.

In fact we know now that many improvements on the system could be made if certain important physical parameters were better known and if a few transformation were made to the system. These concern specially the lamp oscillator and the temperature coefficient of the buffer gas and cavity. In the present design the lamp temperature fluctuations influences directly the maser cavity temperature. This in term introduces variations in the maser output frequency. Secondly the presence of the buffer gas could be adjusted to compensate closely the cavity pulling. In fact the temperature coefficient of the cavity is approximately $2.7 \text{ KHz}/^{\circ}\text{C}$ (quartz cavity partially compensated). The effect produced on the output frequency of the maser is obtained through the following relation

$$\Delta\nu_m = \frac{Q_c}{Q_l} \Delta\nu_c$$

For $Q_c \sim 32,000$, $Q_l \sim 5 \times 10^7$ we obtained

$$\Delta\nu_m = -2 \text{ Hz}/^{\circ}\text{C}.$$

since the temperature coefficient of the nitrogen buffer gas is $0.6 \text{ Hz}/^{\circ}\text{C}/\text{Torr}$, a low pressure of nitrogen would be required for proper operation. However the maser maximum gain is obtained at approximately 10 Torr of nitrogen and it is not known yet if the maser can operate satisfactorily at such a low pressure. It is probable that a wise solution would be to use a mixture of gazes in which the

nitrogen pressure would be maintained at about 10 Torr while its temperature coefficient would be reduced by the addition of a gas with a negative temperature coefficient such as Argon.

These points remain to be investigated in detail and are part of another project in this laboratory.

ACKNOWLEDGMENT

The authors would like to express their sincere thanks to MM. C. Prince and Y. Chalifour for their help in the construction of the maser and the electronic systems. This work was sponsored by the National Aeronautics and Space Administration, the National Research Council of Canada and the department of Education of the Province of Quebec.

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- 1) "Short term Frequency Stability of the Rb^{87} maser", M. Têtu, G. Busca and J. Vanier, IEEE Trans. IM., 22, 250, 1973.
- 2) "Etudes de cavités électromagnétiques perturbées par un diélectrique: Application aux masers", M. Tessier et J. Vanier. Can. J. Phys., 49, 1482, 1971.

- 3) "Relaxation in Rb^{87} and the Rubidium Maser", J. Vanier. Phys. Rev. 168, 129, 1968.
- 4) "Further Results on the Rubidium 87 Maser Frequency Standard", W.A. Stern and R. Novick. Proc. 26th Annual Symposium on Frequency Control, Fort Monmouth, N.J., p. 223, 1972. Available from Electronic Industries Association, 2001 Eye Street, N.W., Washington D.C. 20006.

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IMPORTANT NOTICE

The results given in this report refers to a maser using quartz storage bulbs manufactured prior to 1969. Those bulbs could be operated at approximately 60°C without condensation of rubidium on their inner surface. Bulbs fabricated recently (after 1970) have showed marked differences in behaviour. These last bulbs require an operating temperature of about 90°C in order to prevent rubidium condensation and cavity Q degradation. This point is being investigated extensively and is part of another project.

FIGURE CAPTIONS

- FIGURE 1-a Diagram of the compact rubidium maser Rb-M1.
- FIGURE 1-b Physical appearance of the various parts of the maser.
- FIGURE 1-c Close up view of the bulb lamp and filter cell.
- FIGURE 1-d The maser assembled and mounted in its transportable cart.
- FIGURE 1-e The complete unit including the control electronics and the receiver.
- FIGURE 2 Circuit of the temperature control used for controlling the temperatures of the various points in the maser.
- FIGURE 3 Circuit of the lamp oscillator.
- FIGURE 4 Magnetic field control circuit.
- FIGURE 5 Block diagram of the receiver and VCXO phase lock loop.
- FIGURE 6 Set up used to measure the short term stability of the maser.
- FIGURE 7 Set up used to measure the mean term stability of the maser.
- FIGURE 8 Results of measurements of the stability of the Rb maser.

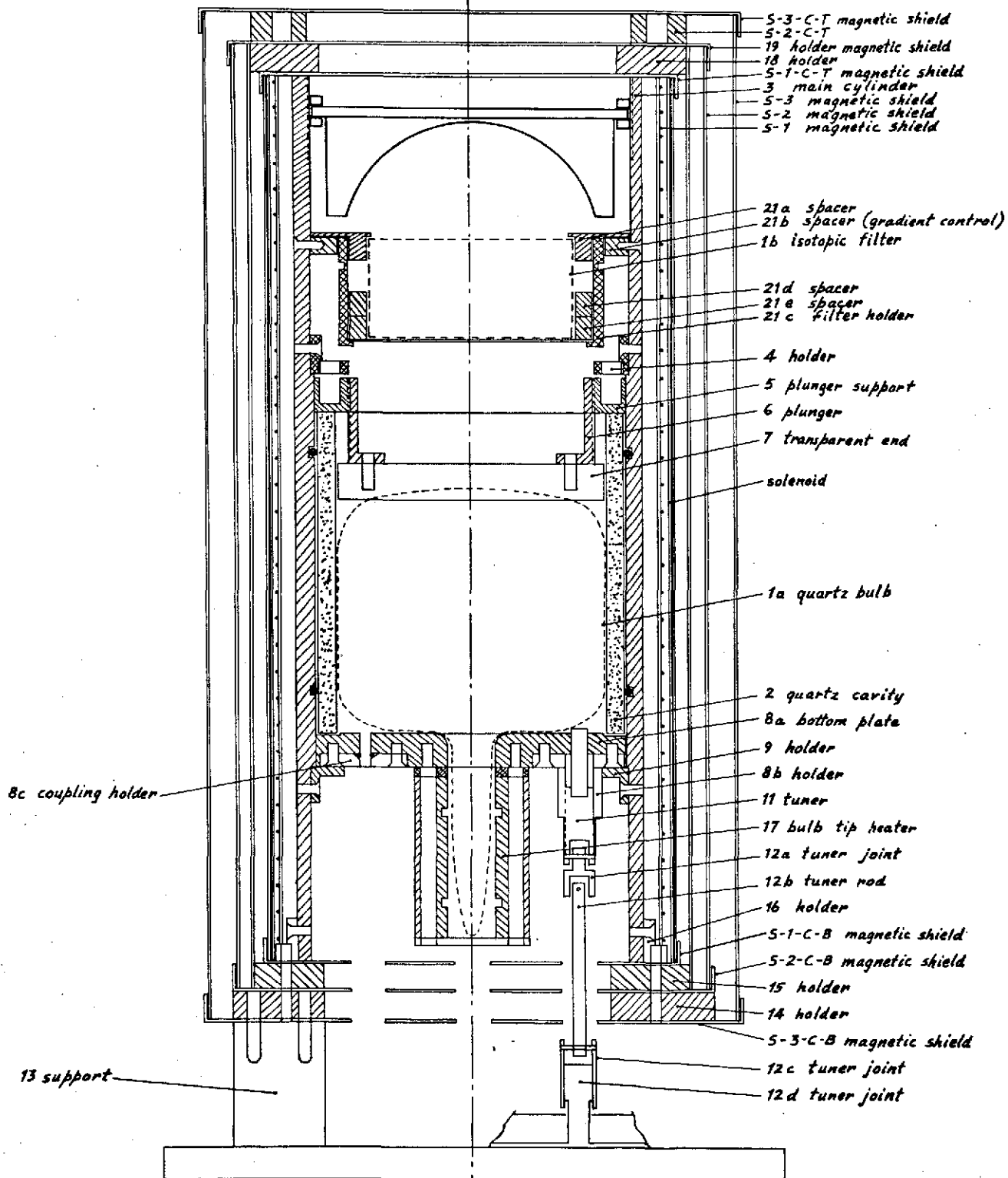


FIGURE 1-a

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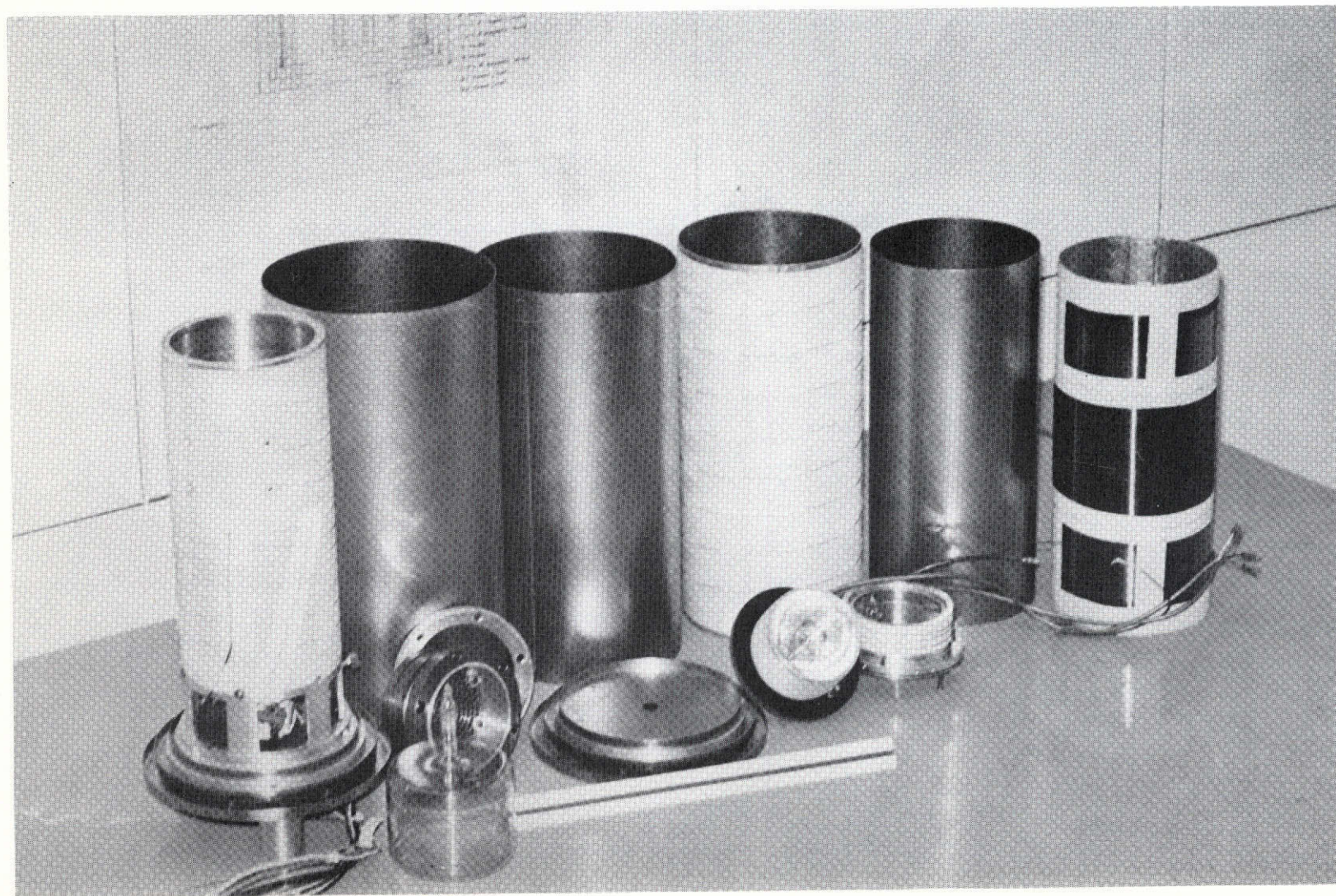
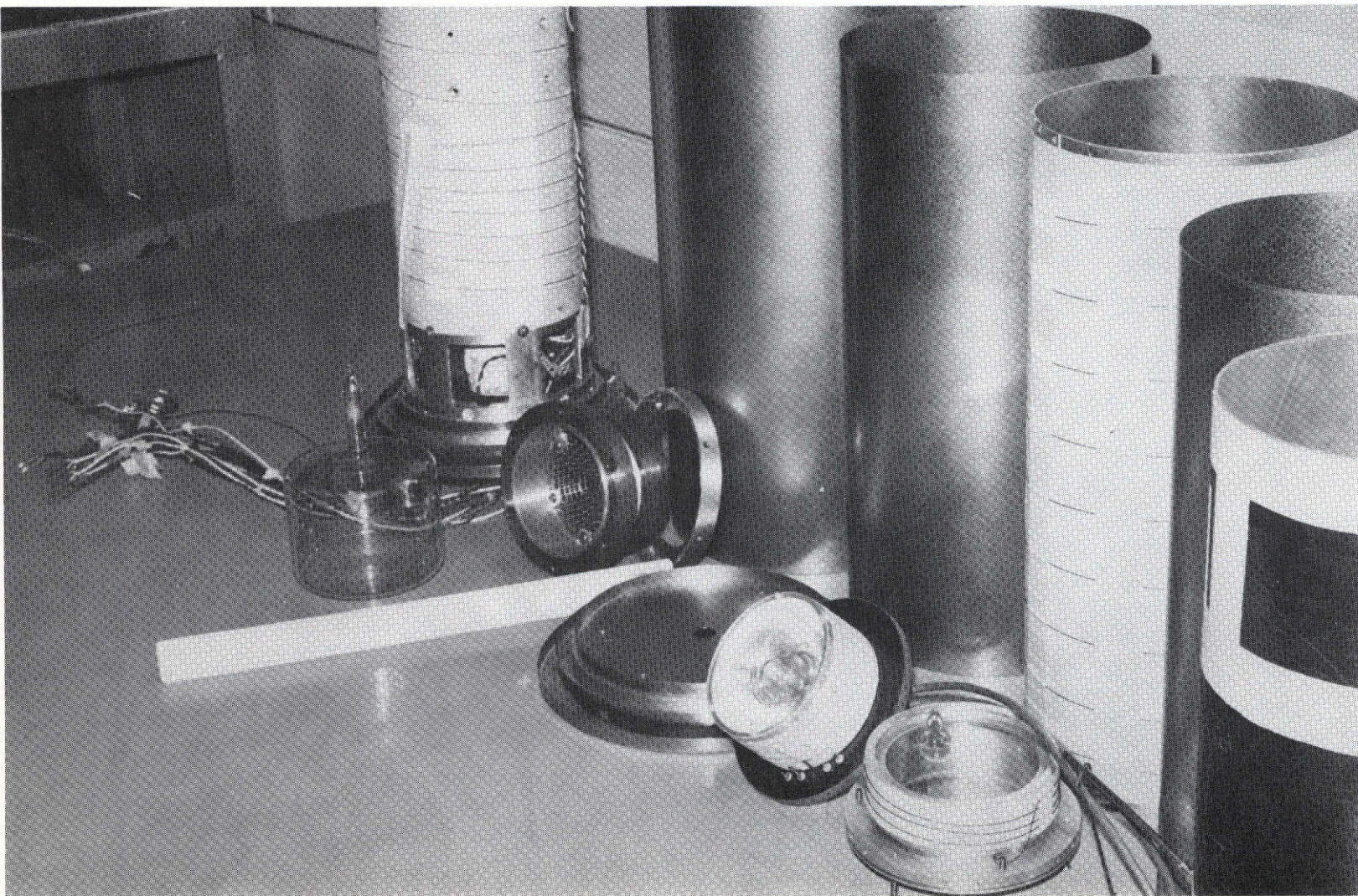
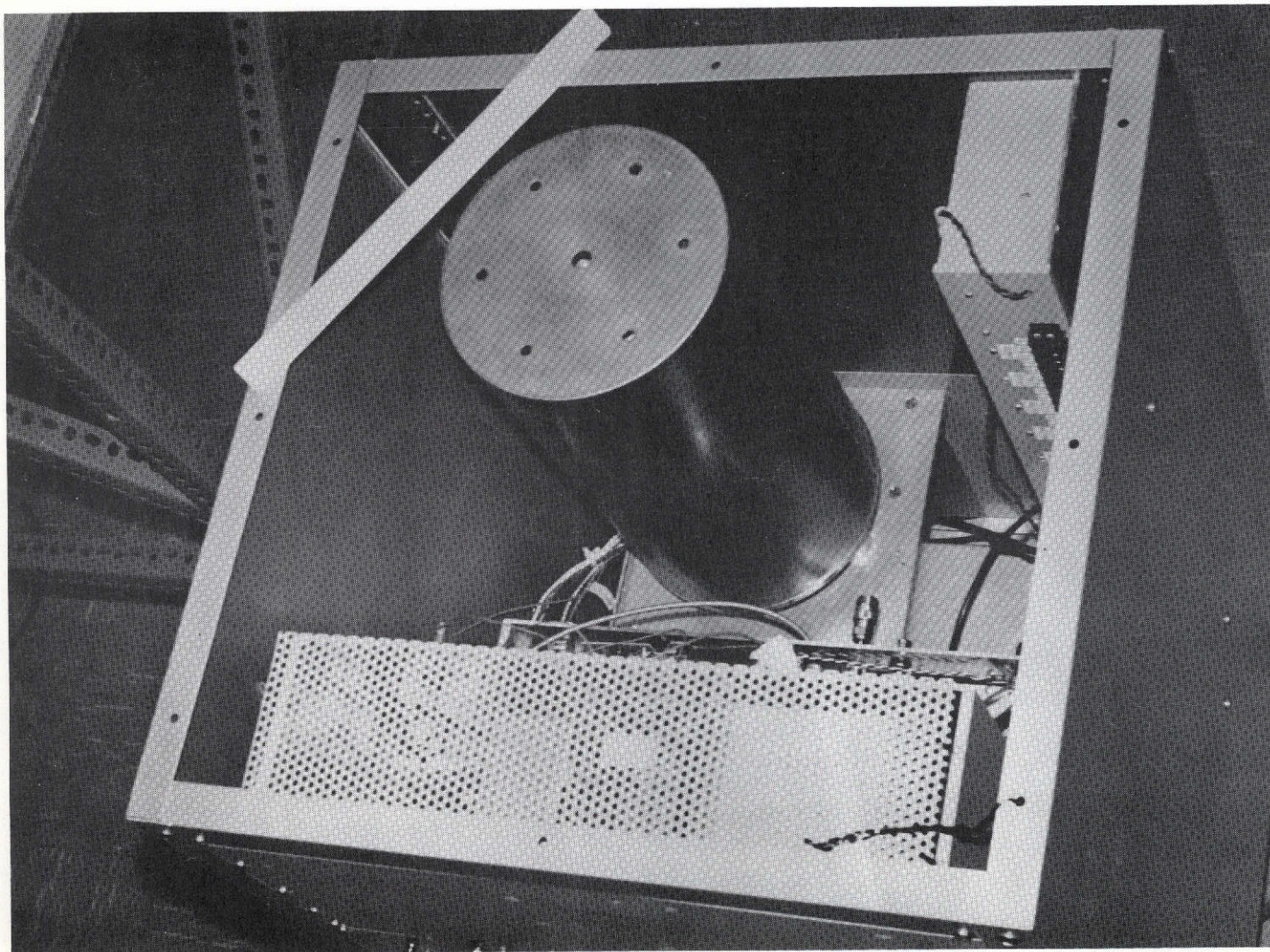
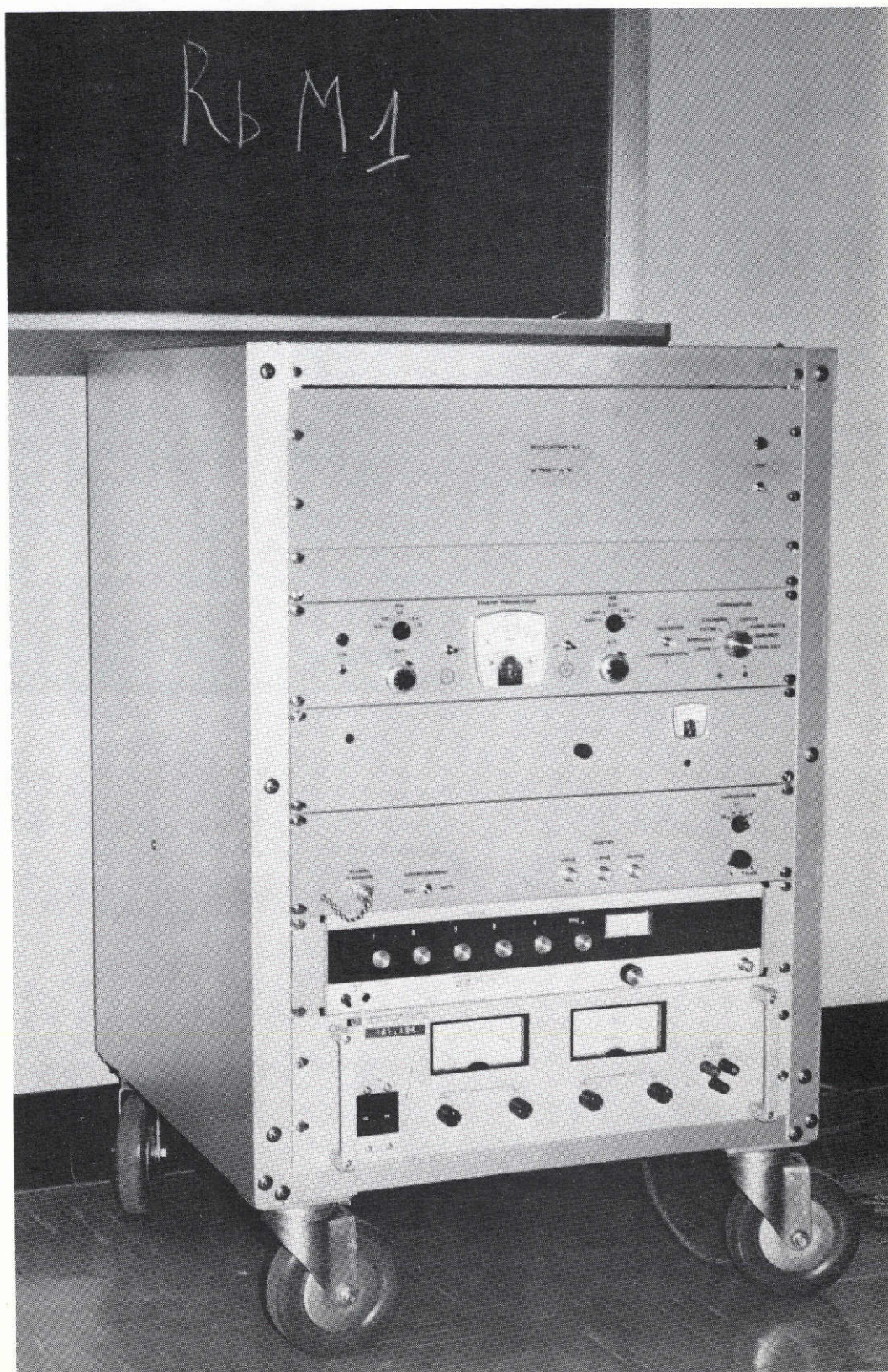


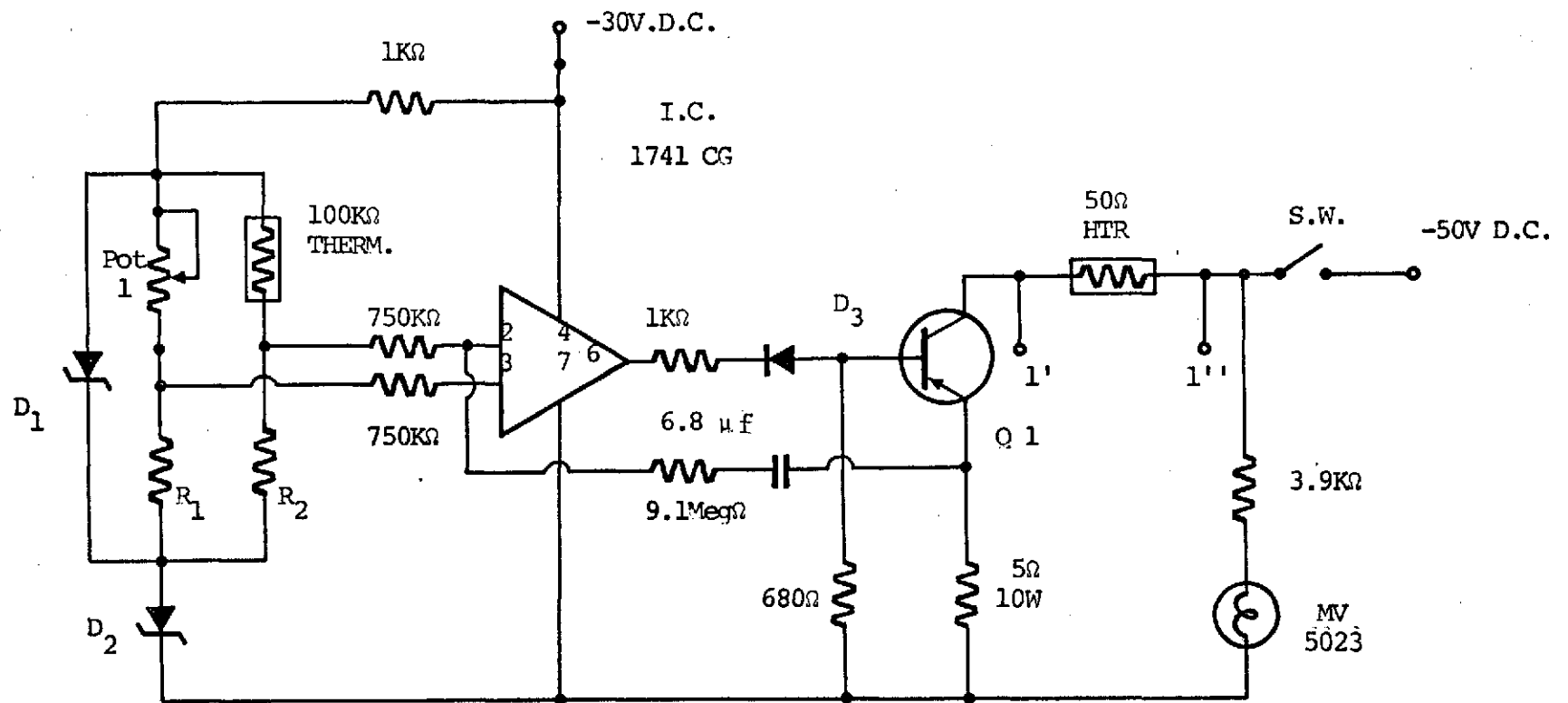
FIGURE 1-b





1-d





Q 1 = TIP 145
 Pot 1 = 50 KΩ 10 Tours
 D 1 = D 2 = Zener 10 V.
 R 1 = R 2 = 10 KΩ 1%
 D 3 = 1N4007

FIGURE 2

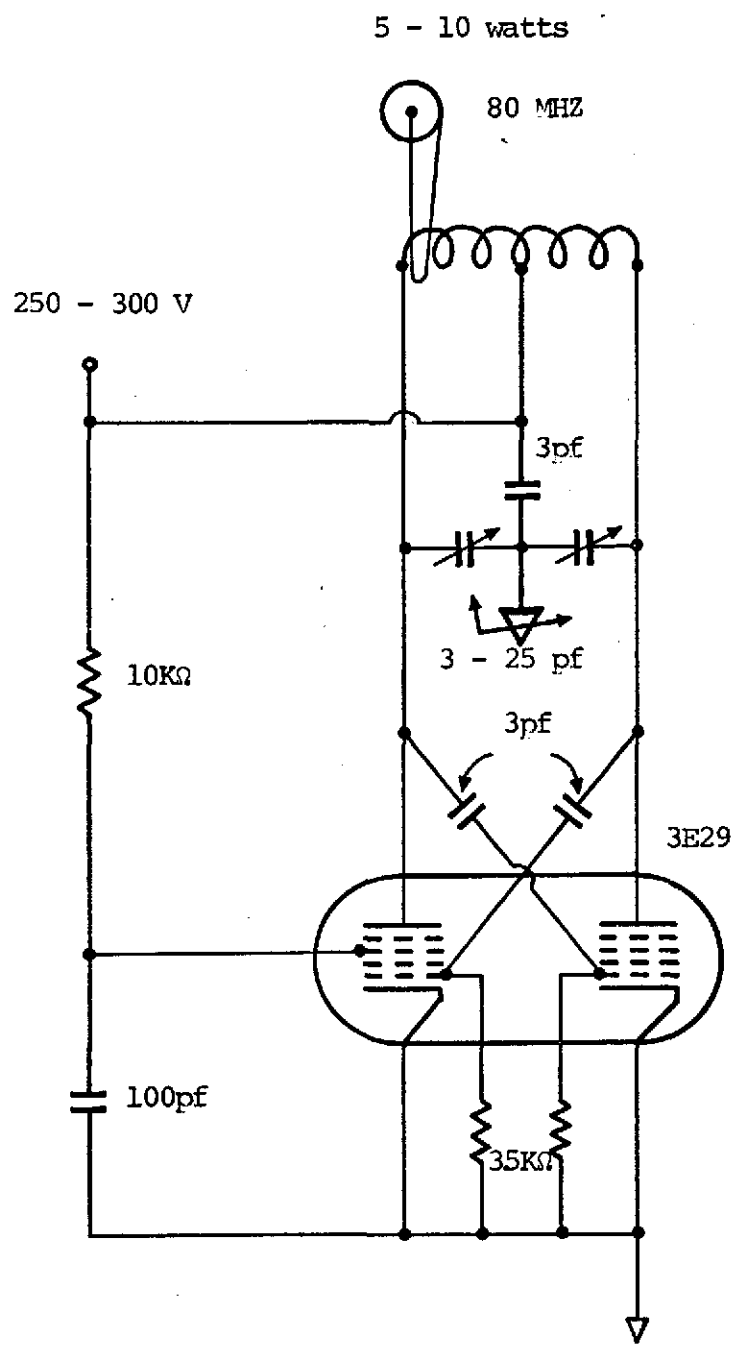
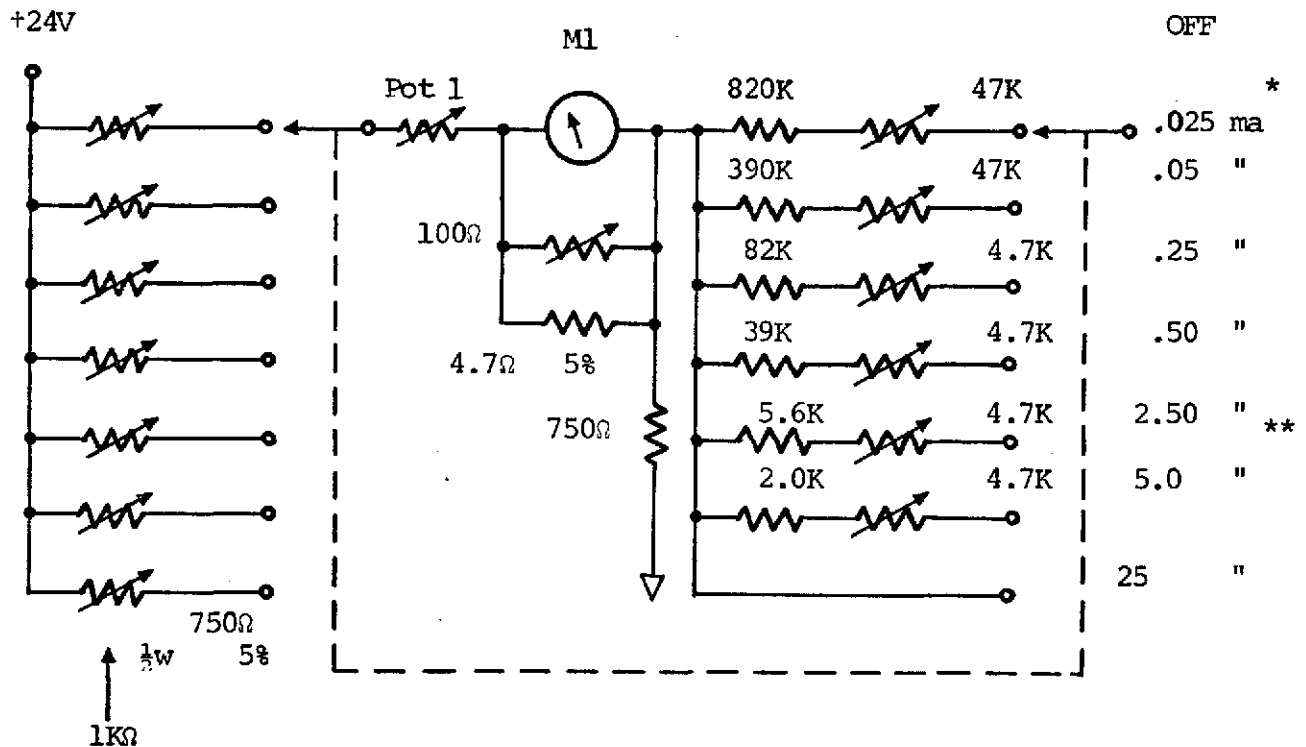


FIGURE 3



Pot 1 - 10KΩ 10 turns

M1 - ARMACO 5A (shunt removed)

The same circuit is used for controlling either the correction coil or the main solenoid.

* - used on first order correction coil

** - used on main solenoid.

FIGURE 4

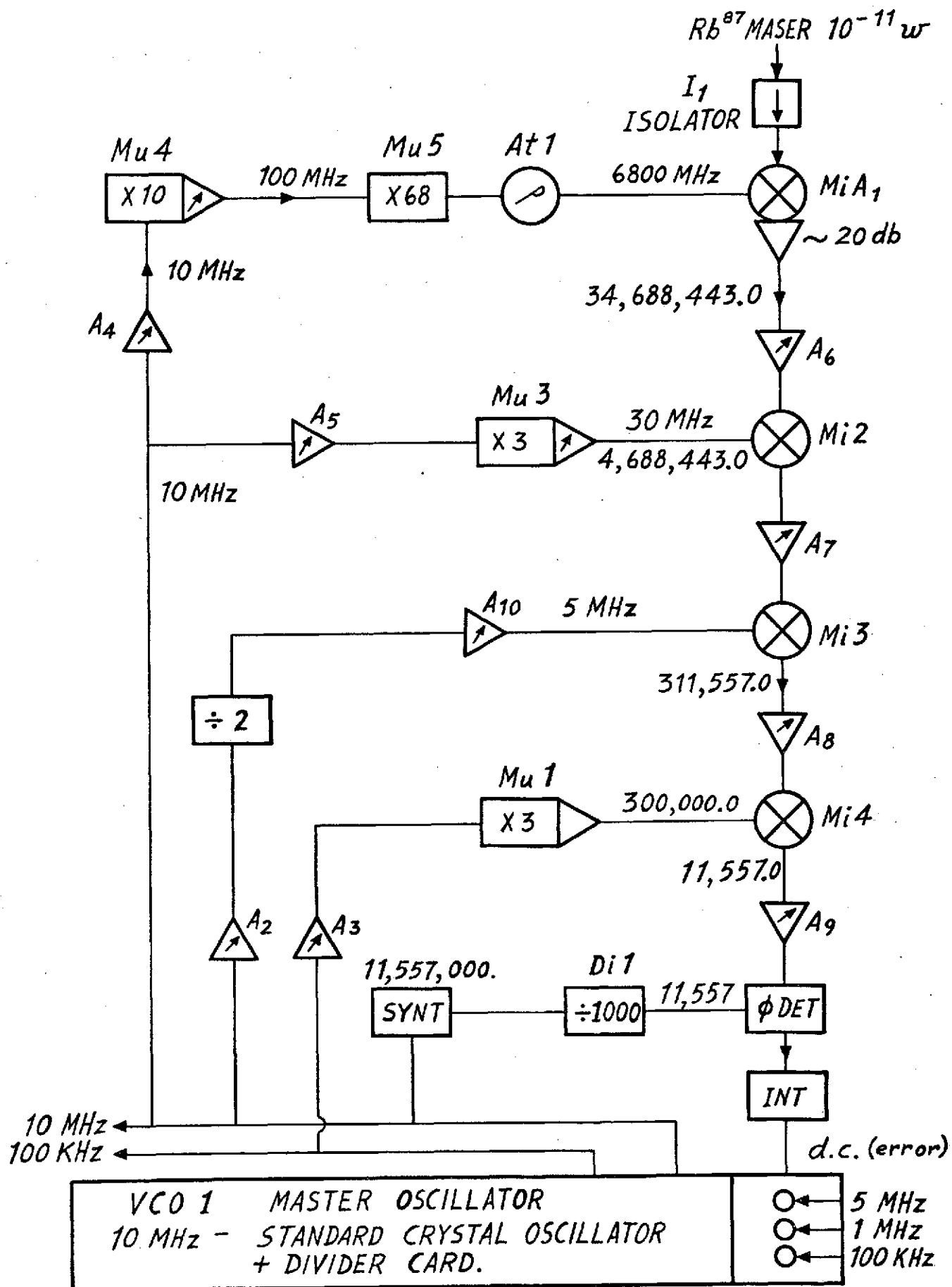


FIGURE 5

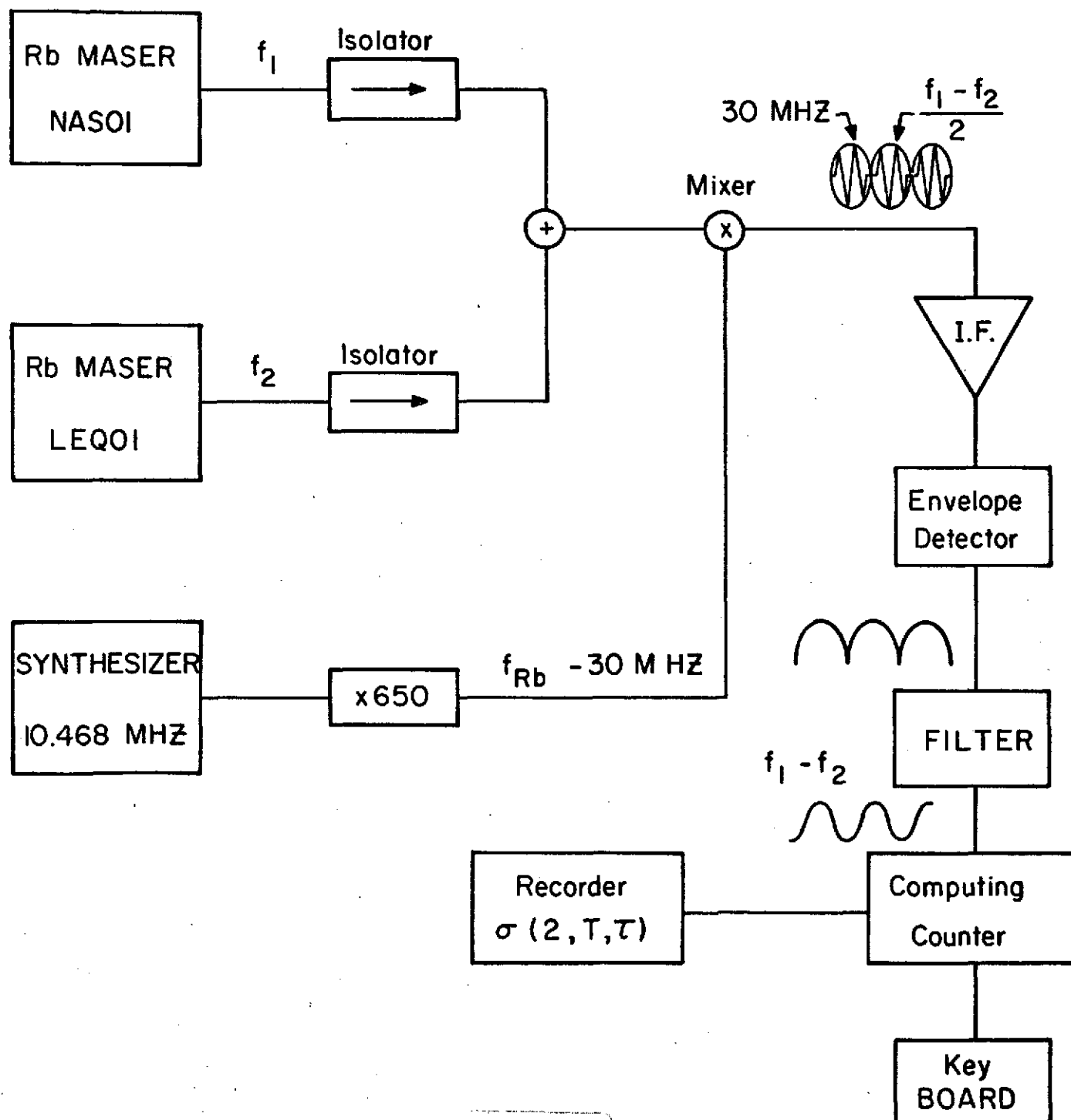


FIGURE 6

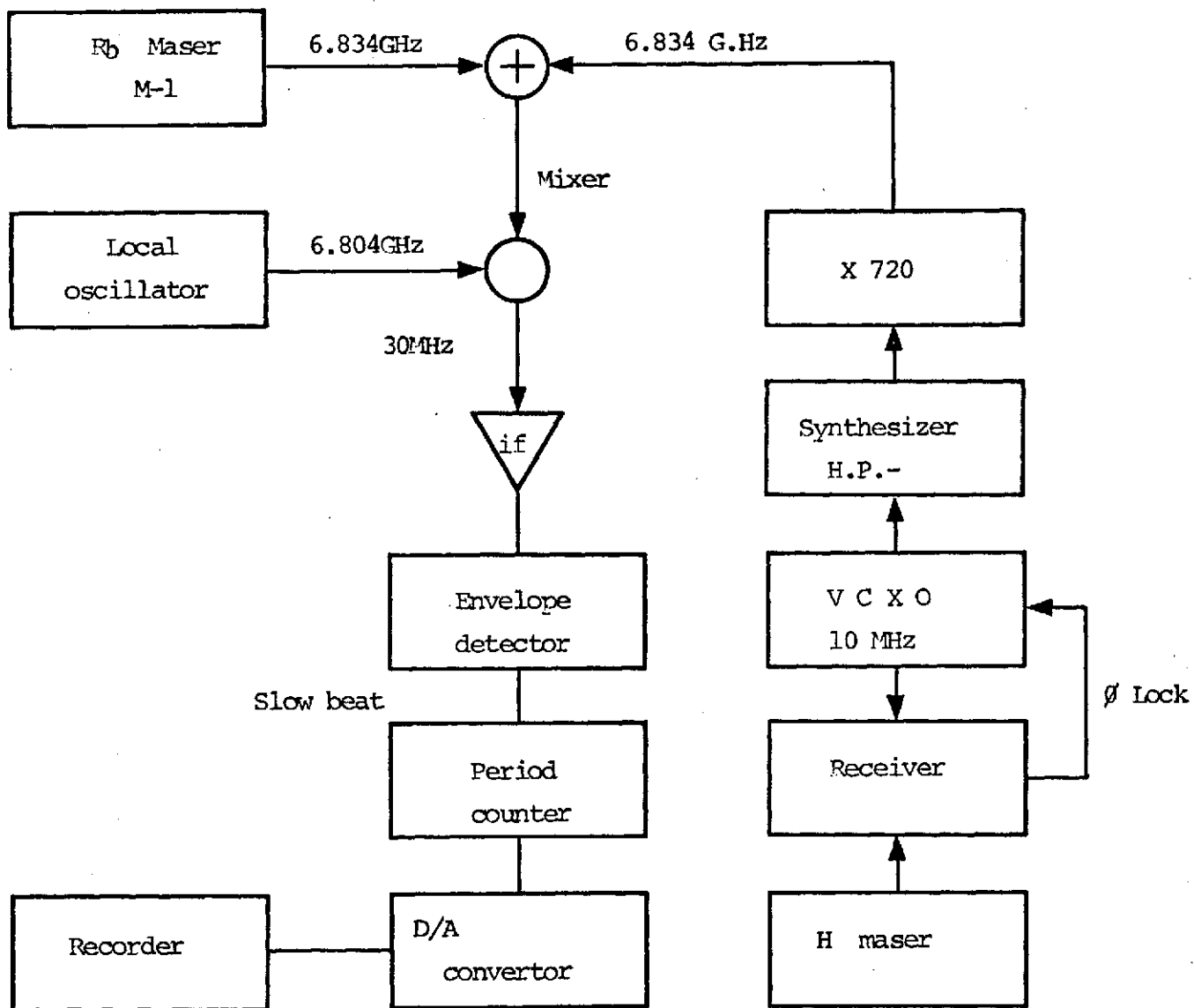


FIGURE 7

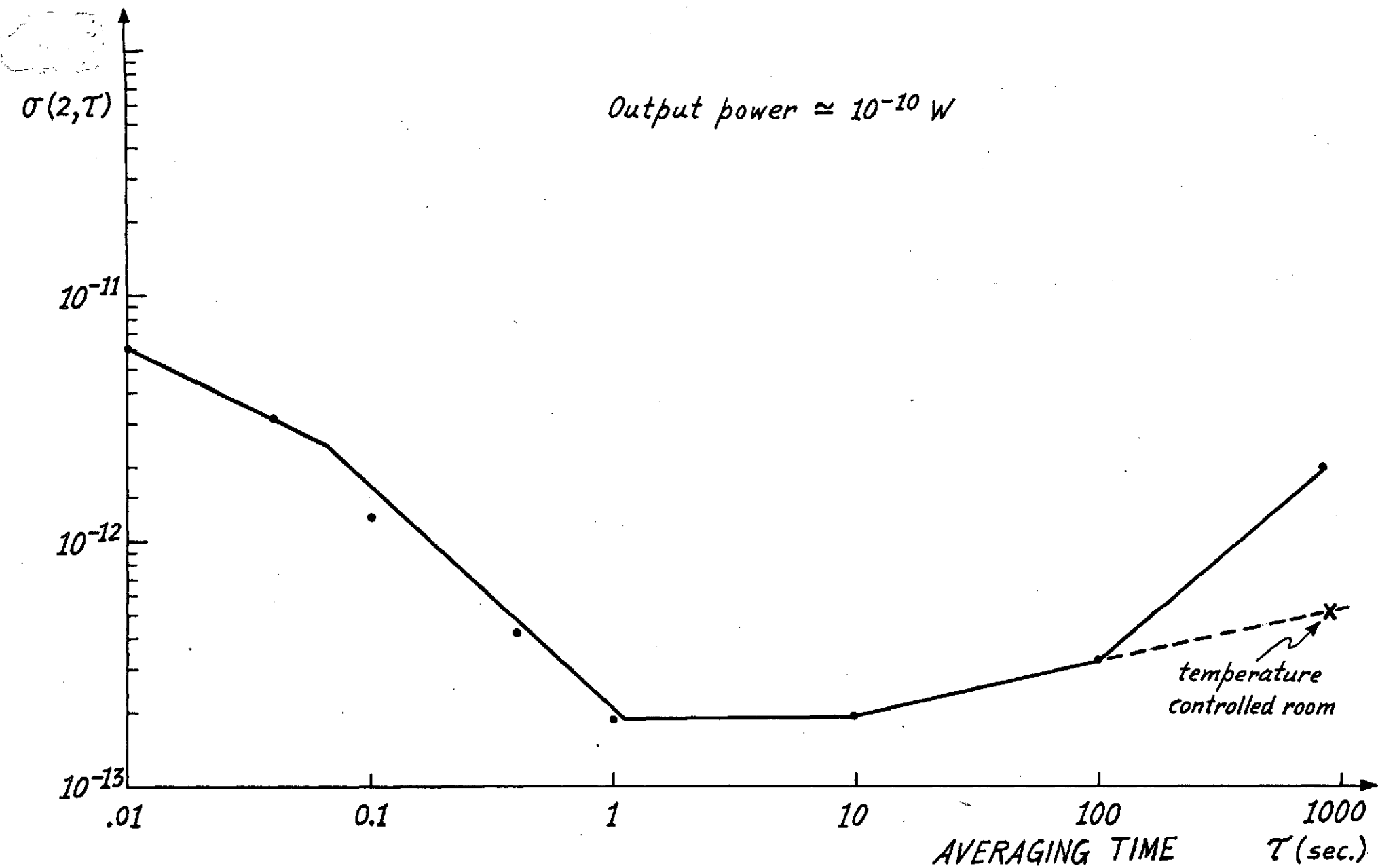


FIGURE 8

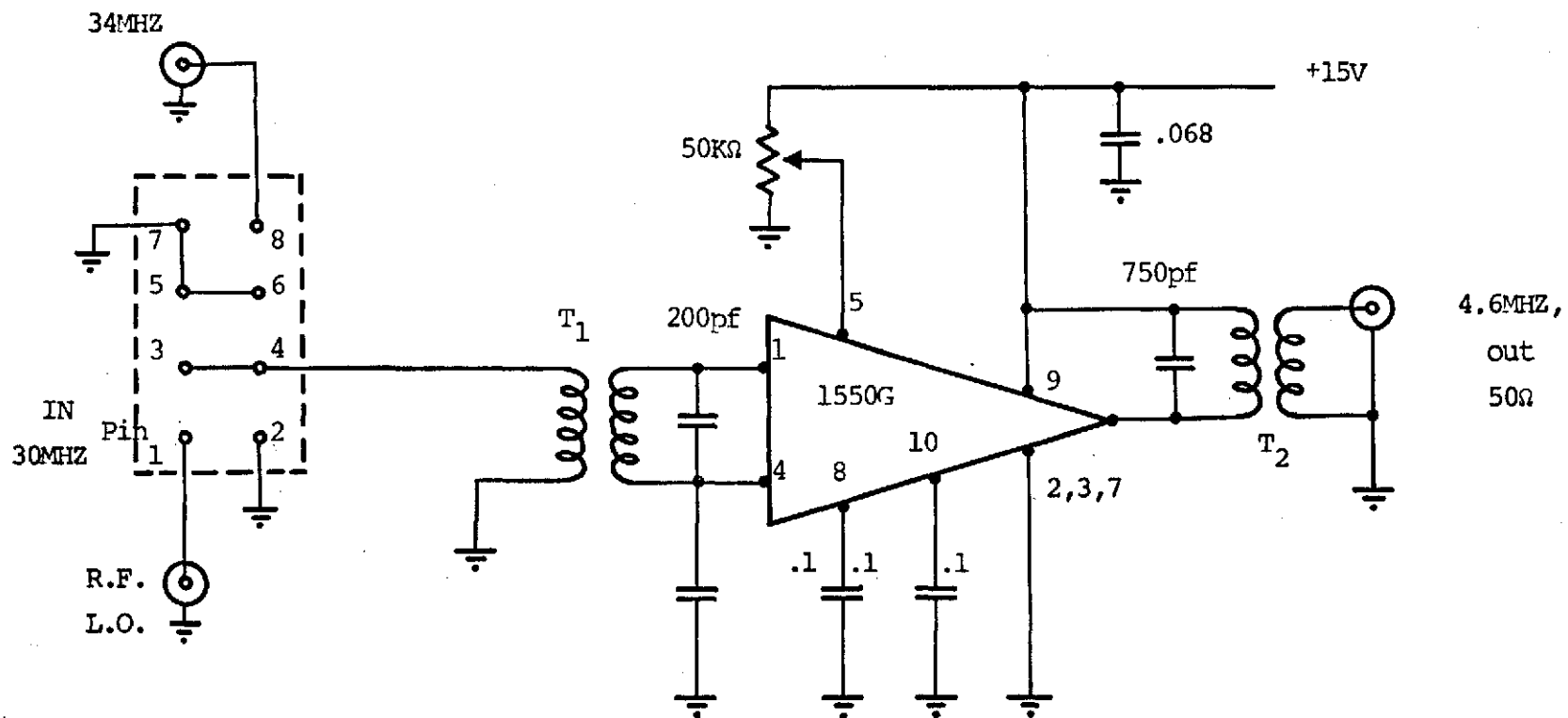
ANNEXE B

Drawings of the main electronic circuits entering into
the receiver section.

MIXER

MCL SRA-6

IN SIGNAL



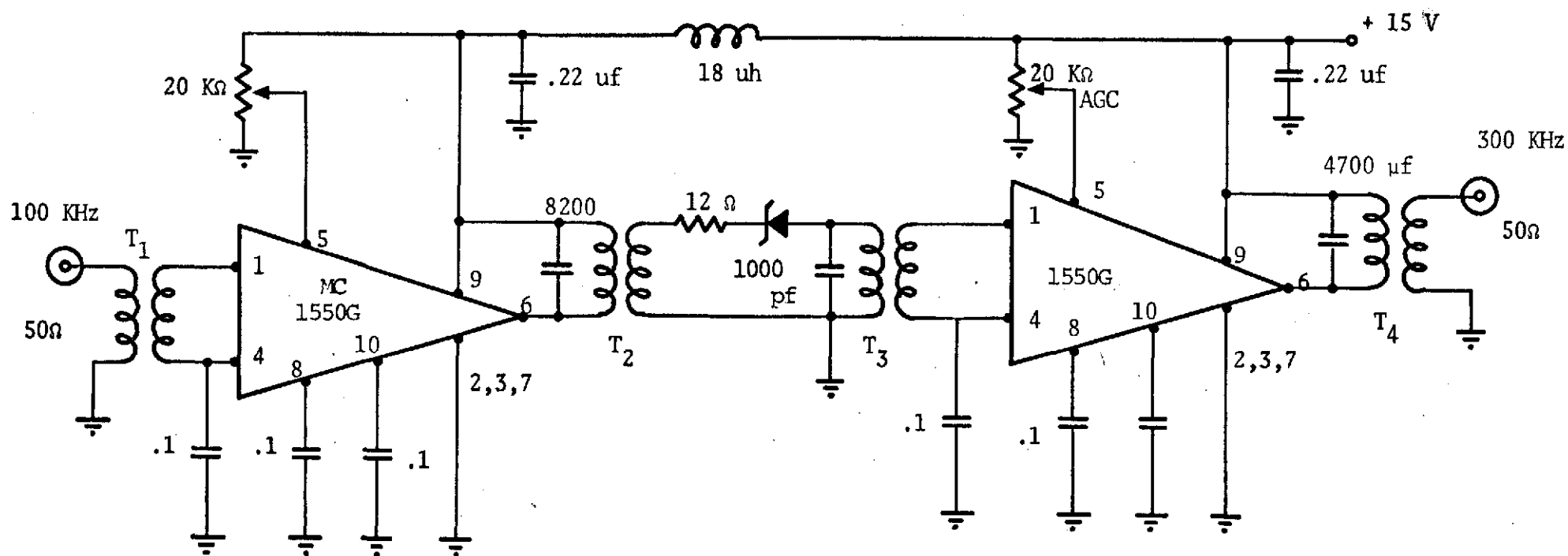
T_1 = prim. 50t
sec. 50t

#36

T_2 = prim. 21t
sec. 6t

Mi 2 and A7

28



T₁ = prim. 300t
sec. 100t

#36

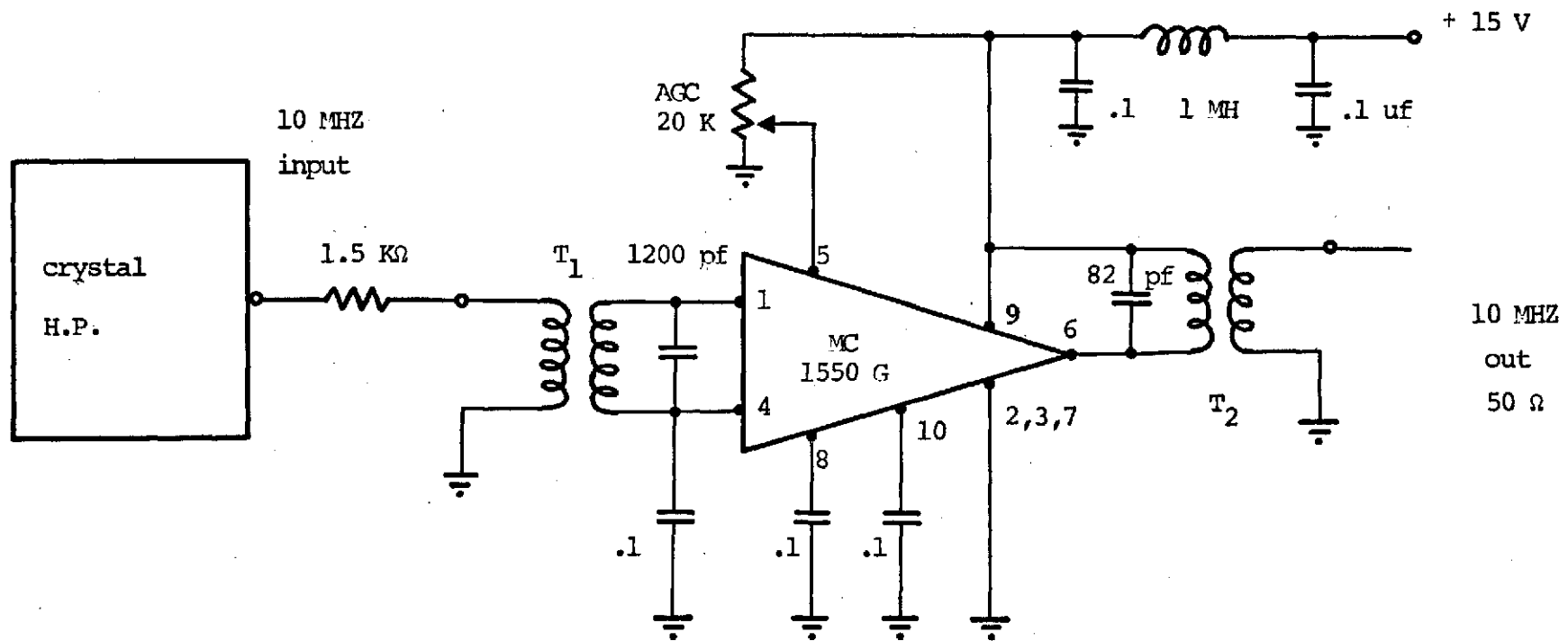
T₂ = prim. 300t
sec. 100t

T₃ = prim. 200t
sec. 100t

#36

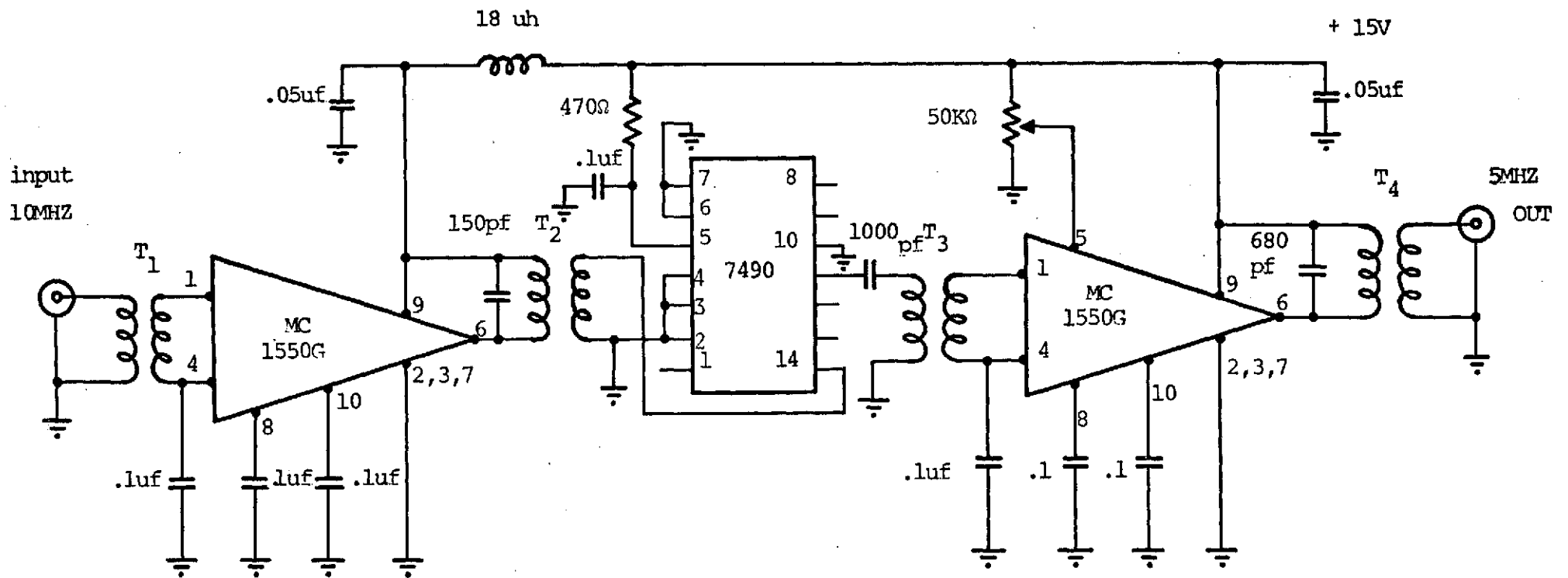
T₄ = prim. 125t
sec. 20t

Mu 1



T ₁	prim.	32 t	# 34
	sec.	6 t	
T ₂	prim.	21 t	# 34
	sec.	5 t	

Isolation Amplifier



T₁ prim. 30t #36
sec. 6t

T₂ prim. 21t #36
sec. 15t

T₃ prim. 100t #36
sec. 21t

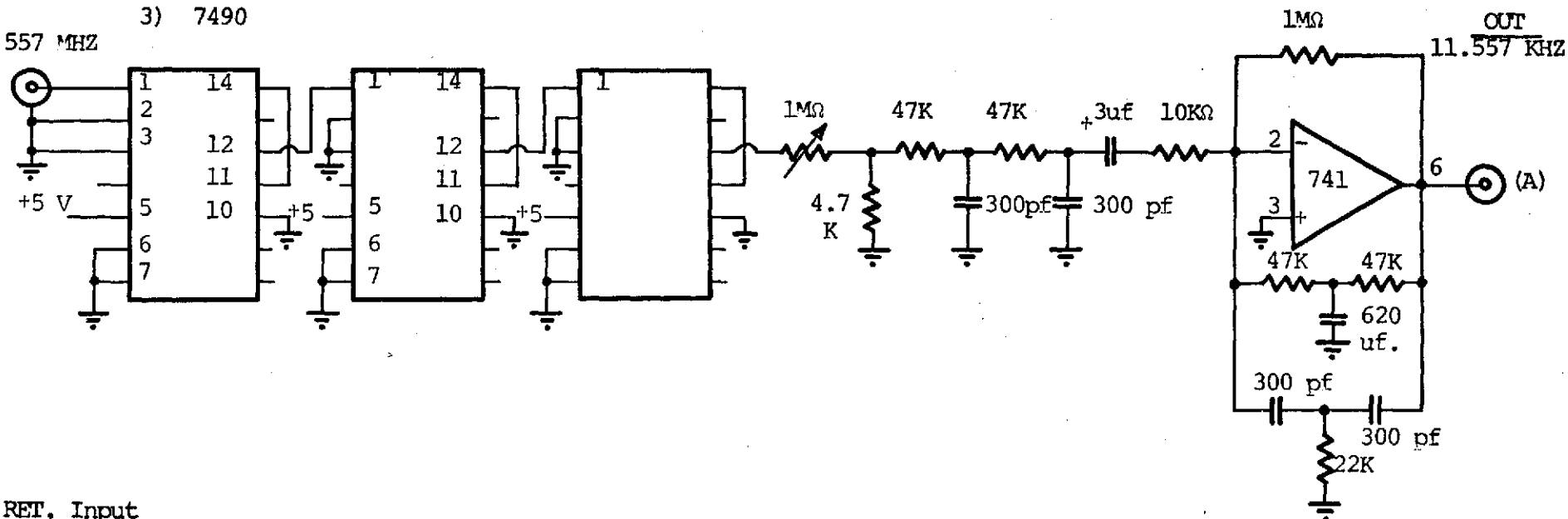
T₄ prim. 21t #36
sec. 7t

Div. by 2 and A10

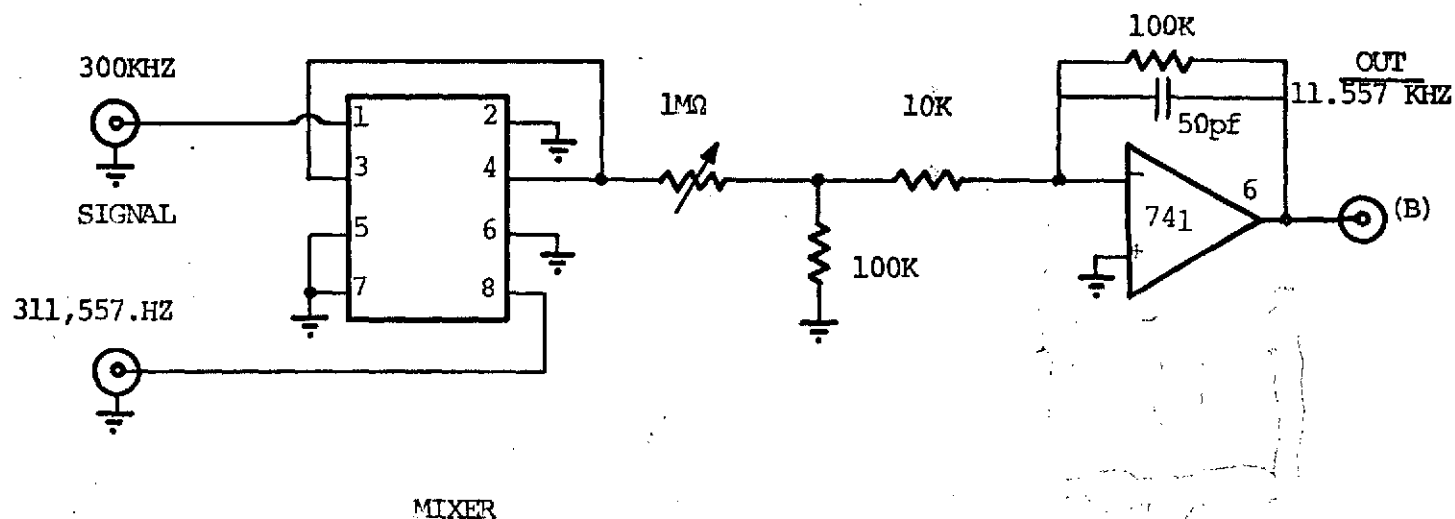
SYNT. Input

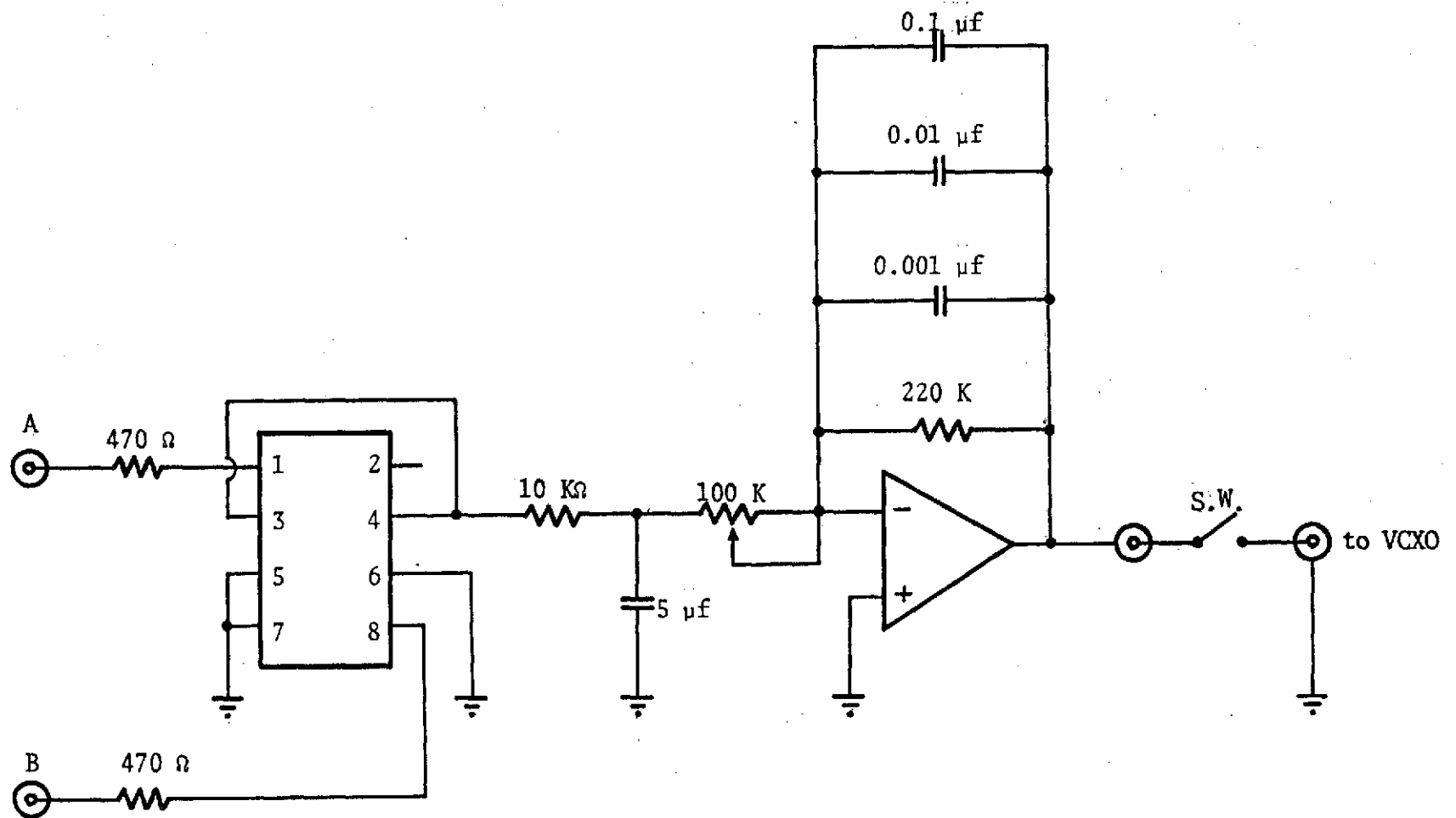
3) 7490

11,557 MHz

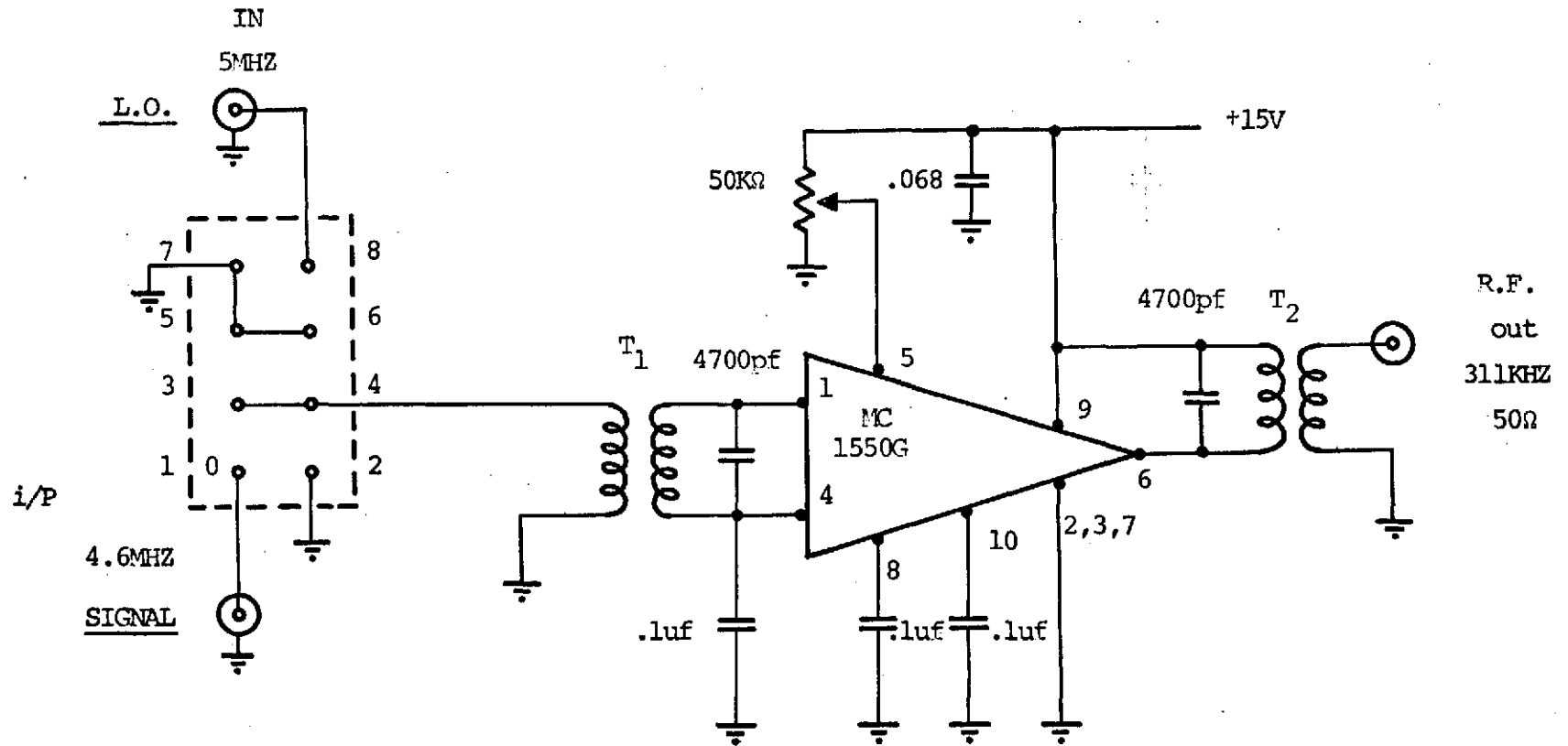


RET. Input





MIXER
MCL SRA-6



T₁ = prim. 125t #36
sec. 125t

T₂ = prim. 125t #36
sec. 27t

Mi 3 and A8

ANNEXE C

Short-Term Frequency Stability of the Rb⁸⁷ Maser.

Paper published in IEEE IM, 22, 250, 1973.

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ANNEXE D

Light Shift Effects in the Rb^{87} Maser.

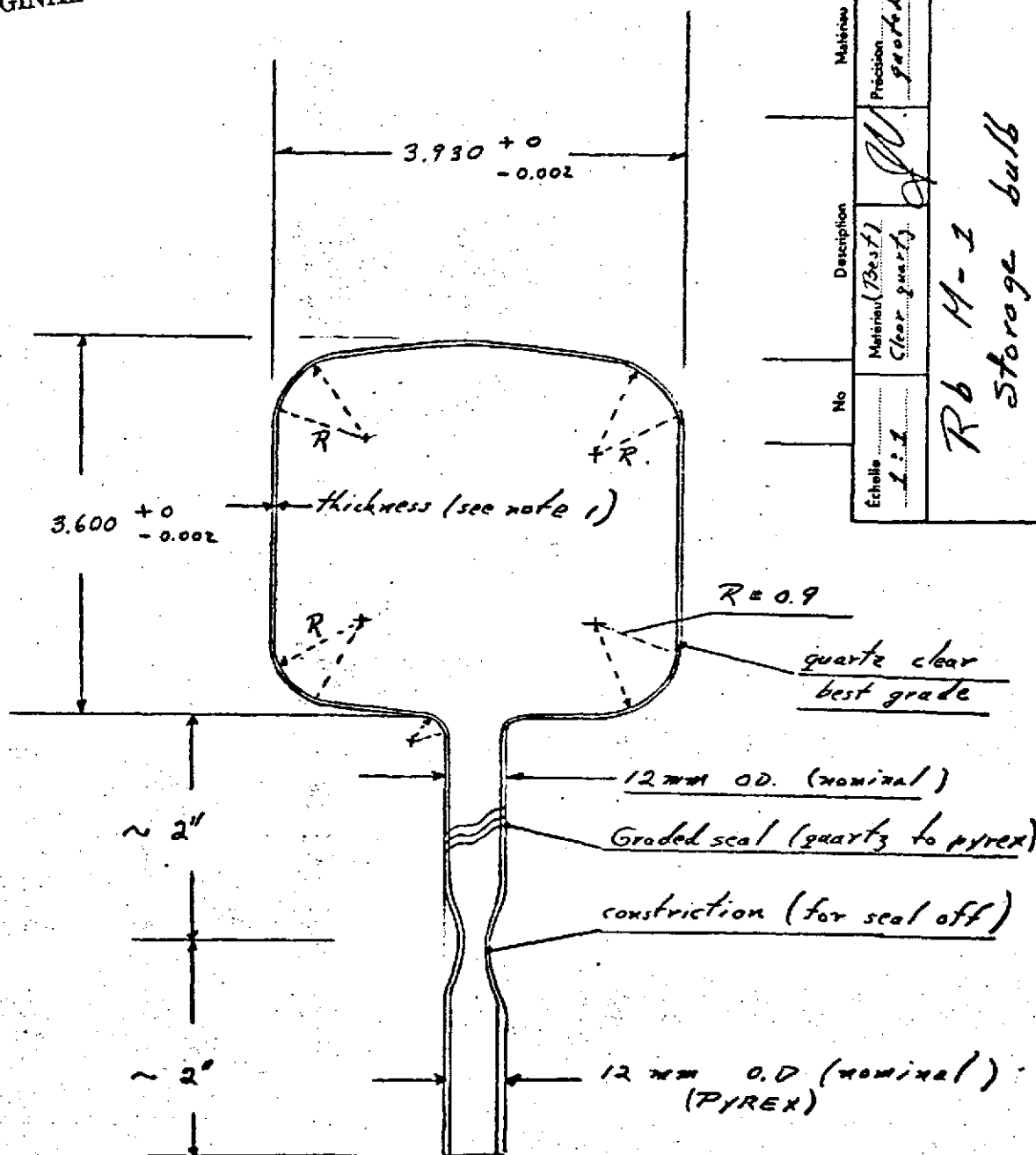
Paper published in Appl. Phys. Lett., 23, 395, 1973.

PAPER INTENTIONALLY OMITTED

ANNEXE A

Drawings of the parts entering in the construction of
the Rubidium maser Rb-M1.

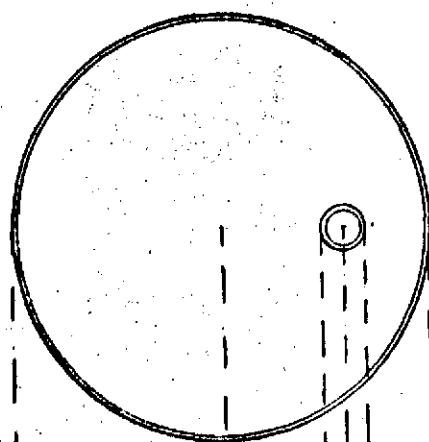
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No	Description	Matériau	Spéc.	Quant.
Échelle 1:1	Matériau (Best)	Précision	LABORATOIRE D'ÉLECTRONIQUE QUANTIQUE	
	Clear quartz		Université Laval Québec 10	
			Date 23/11/74	
			No 44-3	

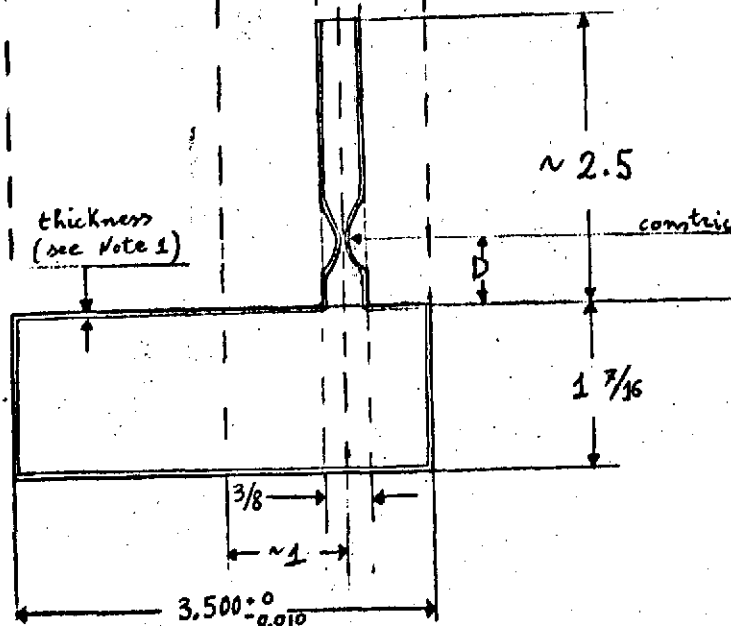
Note 1 the thickness should be of the order of 0.75 mm (or 0.030"). In order to achieve that the total amount of quartz for the bulb alone should not exceed 85 grams.

Note 2 this bulb will be put under vacuum.



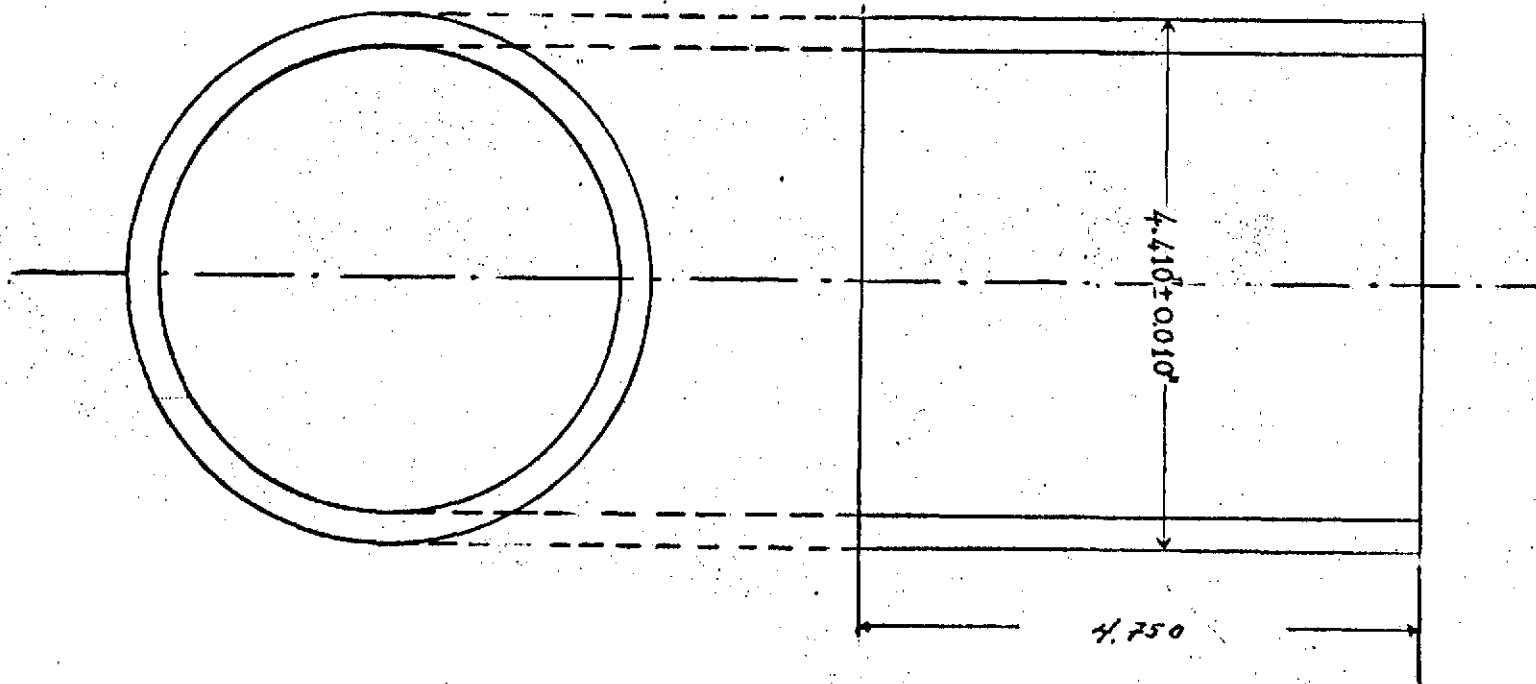
NOTE 1: this bulb will be evacuated.

— give the required thickness —

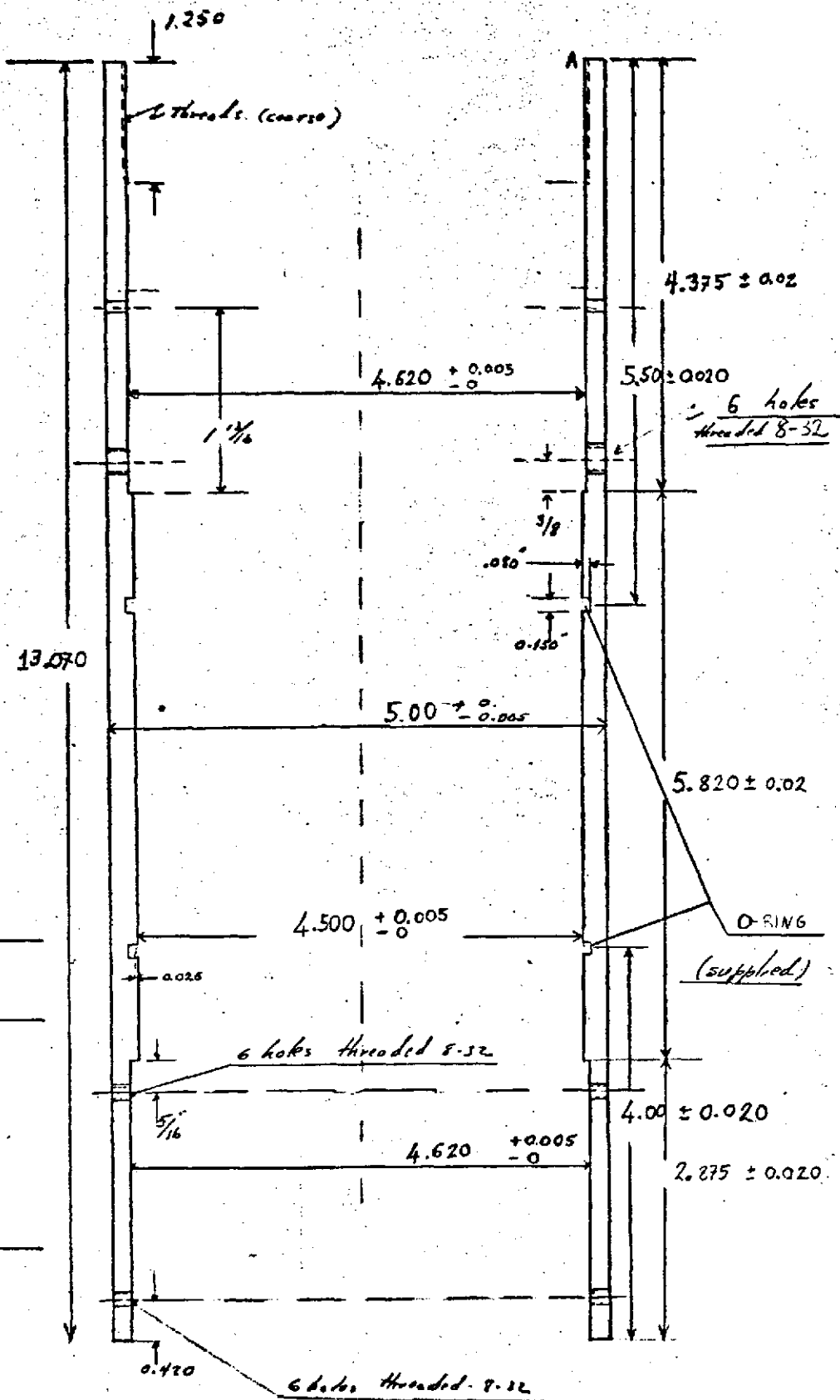


constriction (to seal off). Keep the distance D as short as possible.

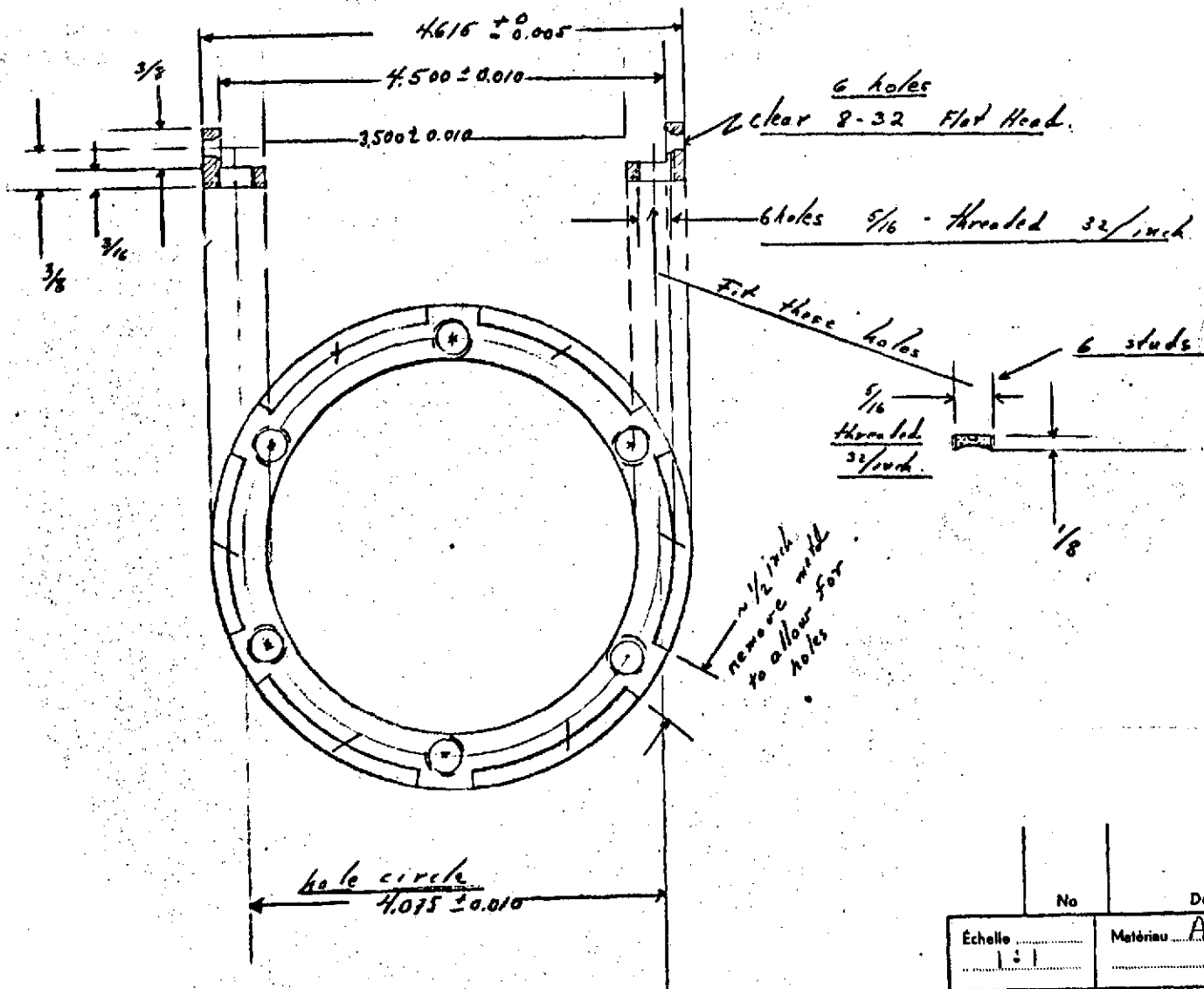
No	Description	Matériau	Spéc.	Quant.
Echelle 1:1	Matériau PYREX	Précision	LABORATOIRE D'ELECTRONIQUE QUANTIQUE Université Laval Québec 10 ^e	
R6 M 1 Isotopic Filter			Date 31-1-73	No 1-b



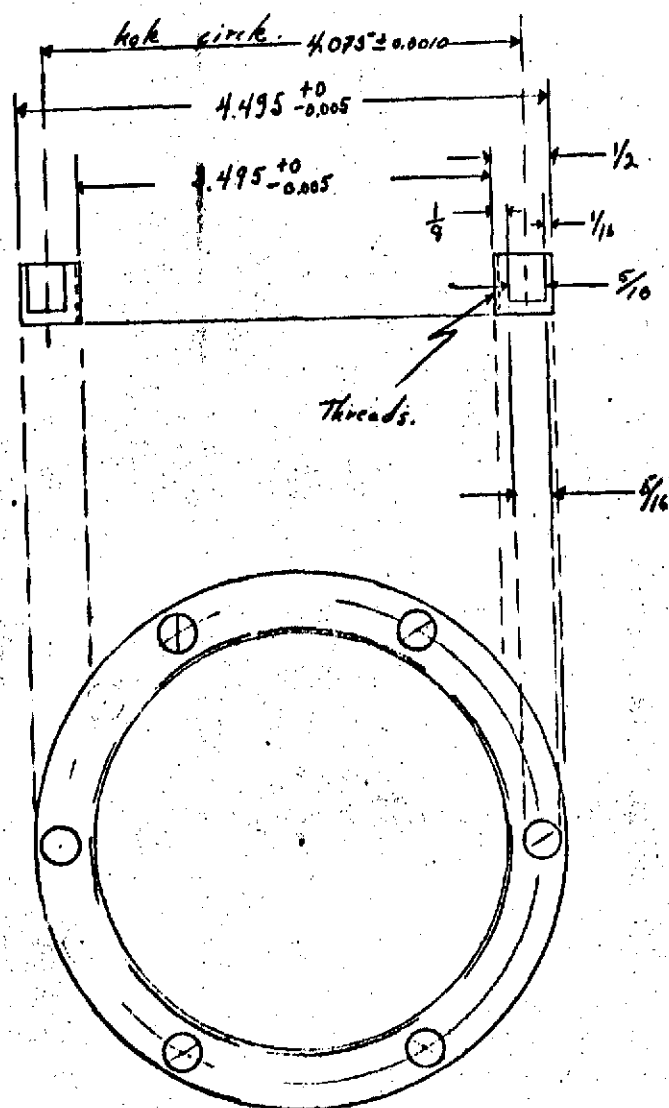
No	Description	Matériau	Spéc.	Quant.
Échelle <u>1:1</u>	Matériau <u>apogut fused-silica</u>	Précision <u>as quoted</u>	LABORATOIRE D'ELECTRONIQUE QUANTIQUE	
R6-M-1 Microwave Cavity			Université Laval Québec 10 ^e	
			Date <u>28-09-72</u>	
			No <u>2</u>	



Rb-M-1	Echelle	Matériau	Description	Matériau	Spec.	Quant.
	1:1					
Main - Cylinder	1:1	AL	6.8	—	LABORATOIRE D'ELECTRONIQUE QUANTIQUE	Université Laval Québec 1P1
	No	Date 10/11/72	No	3		

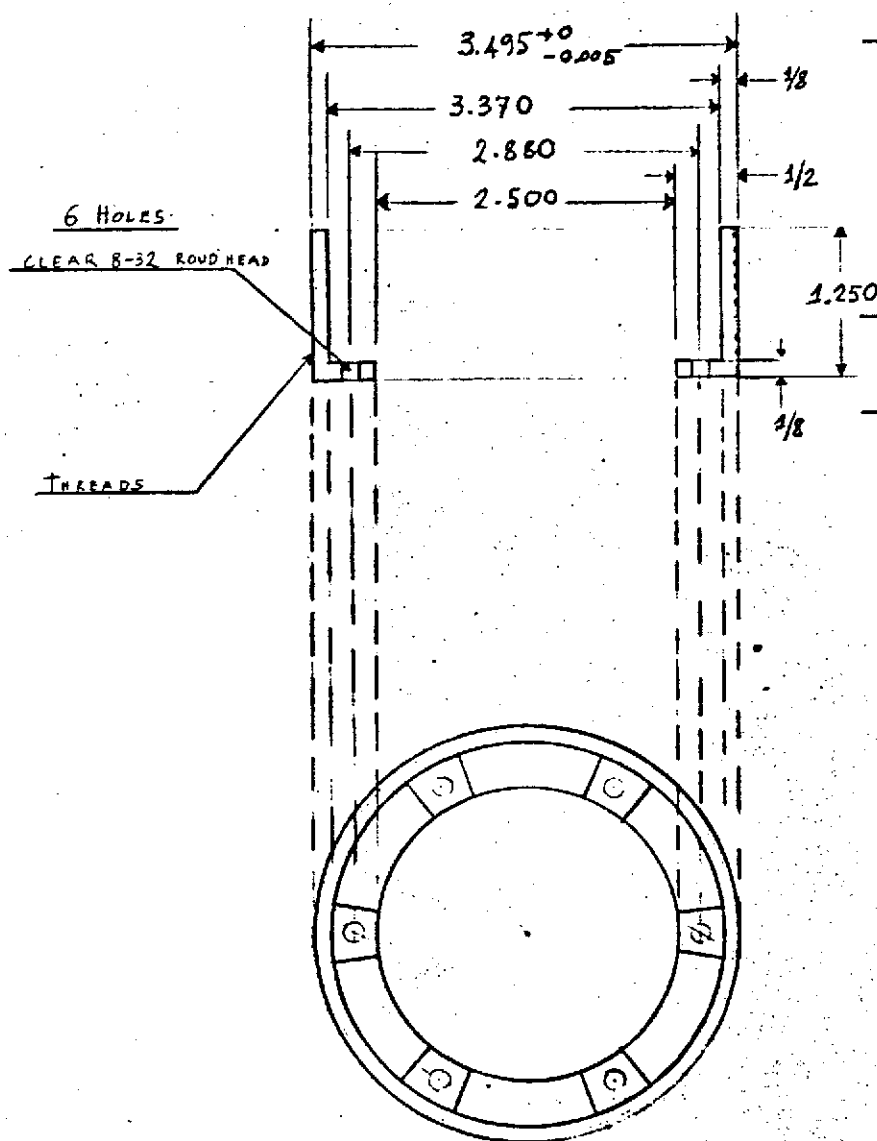


No.	Description	Matériau	Spéc.	Quant.
Echelle 1:1	Matériau AL G.B.	Précision —	LABORATOIRE D'ELECTRONIQUE QUANTIQUE Université Laval Québec 10 ^e	
R6 M-1 Cavity-Spring-Compressor.			Date 12/11/22	No 4



No	Description	Matériau	Spéc.	Quant.
Echelle 1:1	Matériau <u>AL</u>	<u>10</u> <u>G.B</u>	Précision —	LABORATOIRE D'ELECTRONIQUE QUANTIQUE Université Laval Québec 10 ^e
R6 H.1 Cavity Spring Retainer				Date <u>10/11/92</u> No <u>5</u>

47

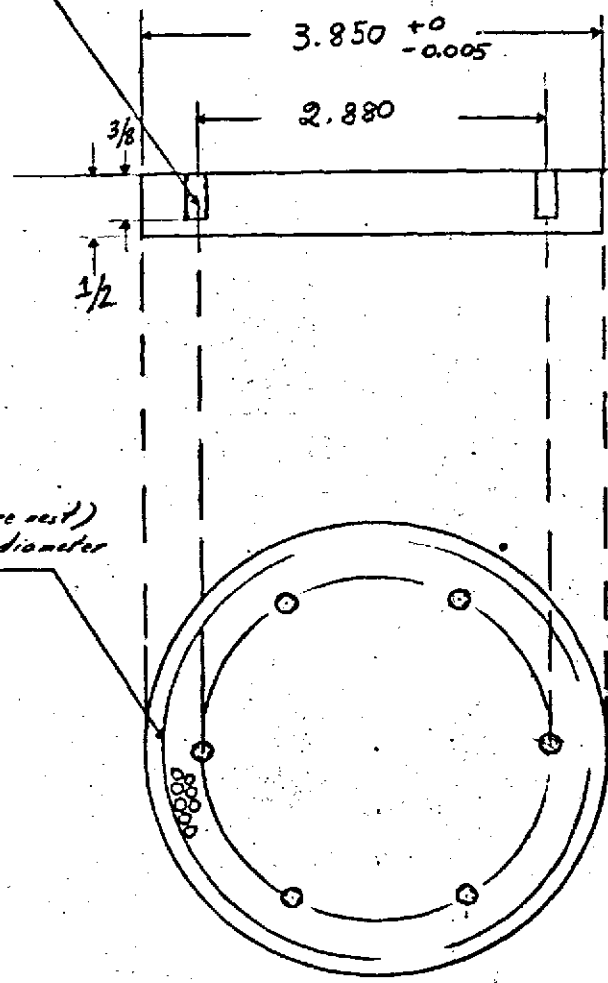


Échelle 1:1	No	Description	Matériau Al or Cu	Précision —	Matériau A.L.	Spéc.	Quant.
R6 M-1							
Cavity Plunger Attachment							
LABORATOIRE D'ÉLECTRONIQUE QUANTIQUE Université Laval Québec 1G							Date 10/11/72
No							6

ESQUISSE

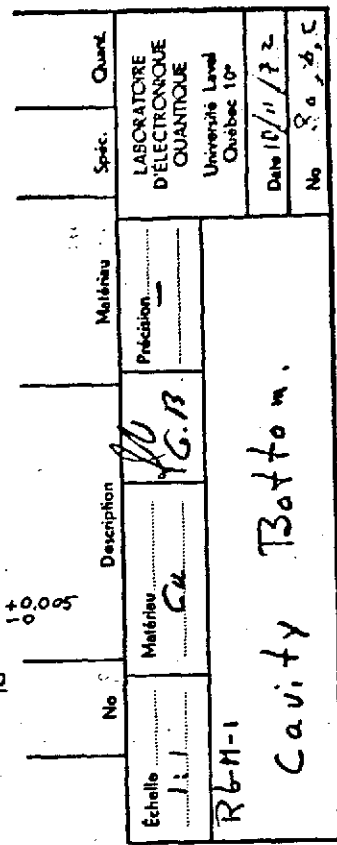
6 holes 8-32 threaded

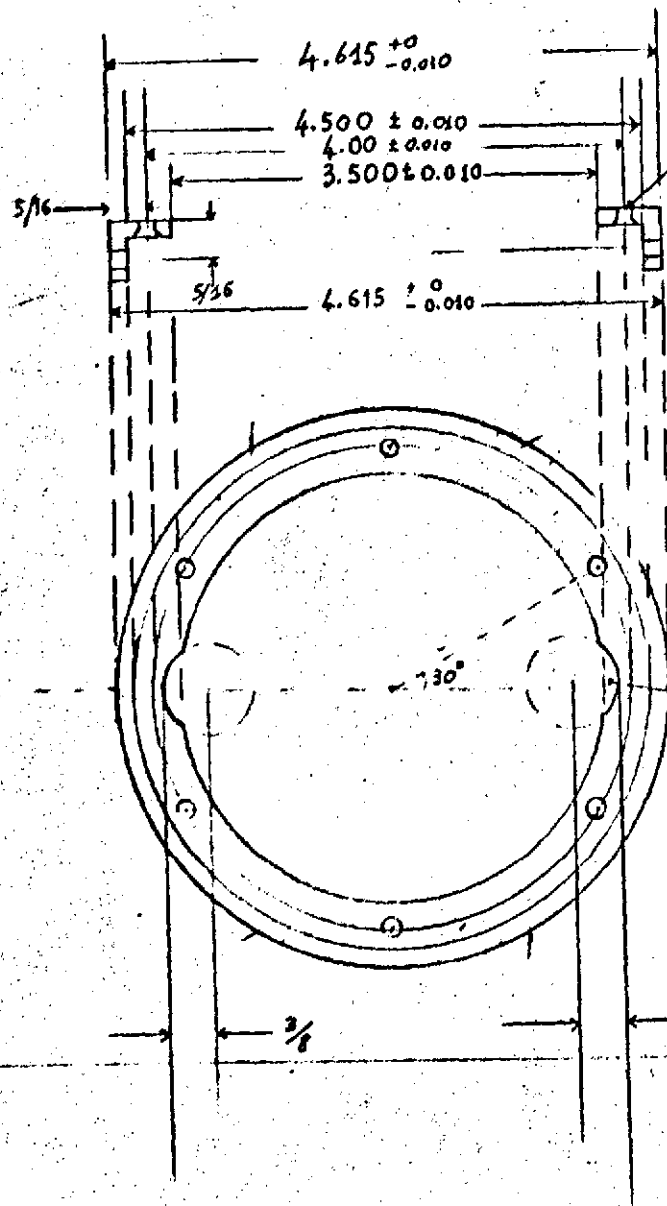
Make holes (see next)
inside this diameter



No.	Description	Matériau	Spéc.	Quant.
Echelle 1:1	Matériau C.A.	Prédiction —	LABORATOIRE D'ELECTRONIQUE QUANTIQUE Université Laval Québec 10 ^e	
Rd n-1		Date 12/11/22		
Cavity Coarse Tamer		No. 7		

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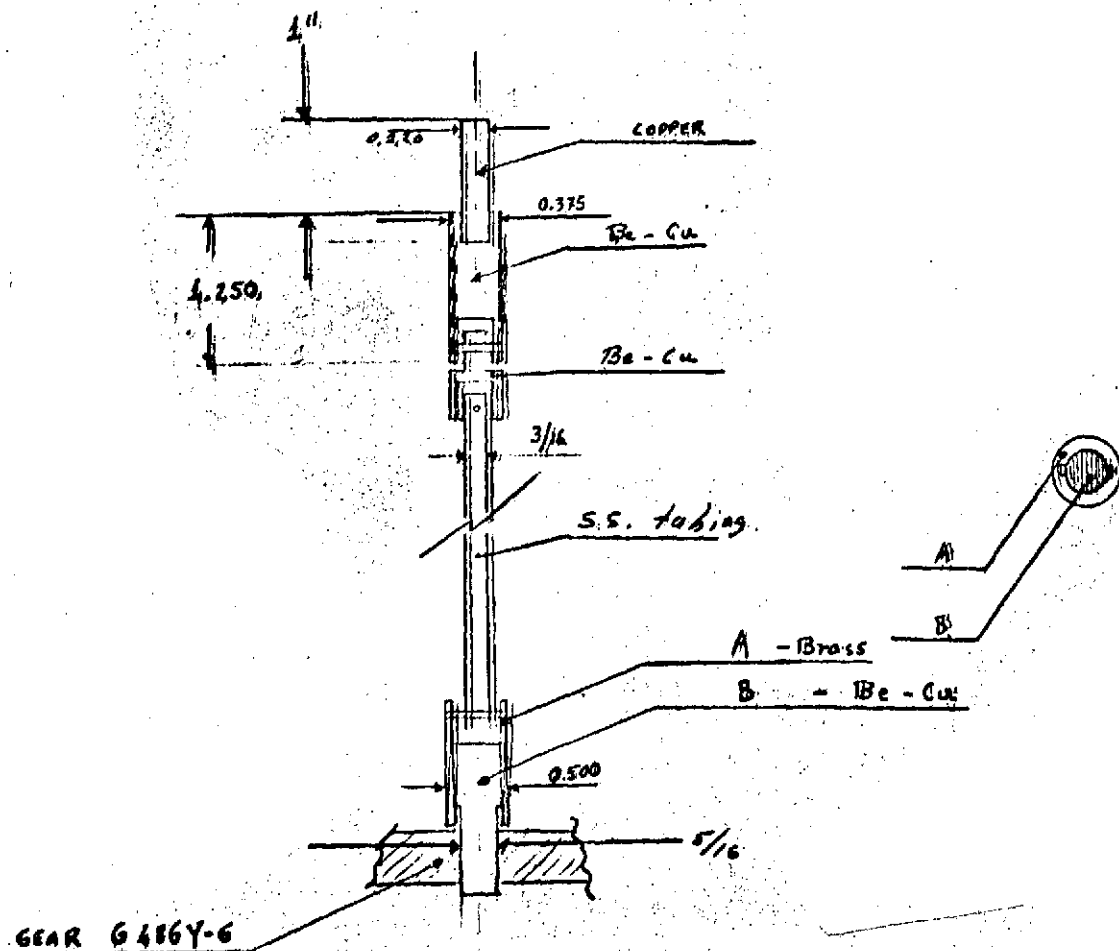
6 HOLES

CLEAR 8-32 FLAT HEAD

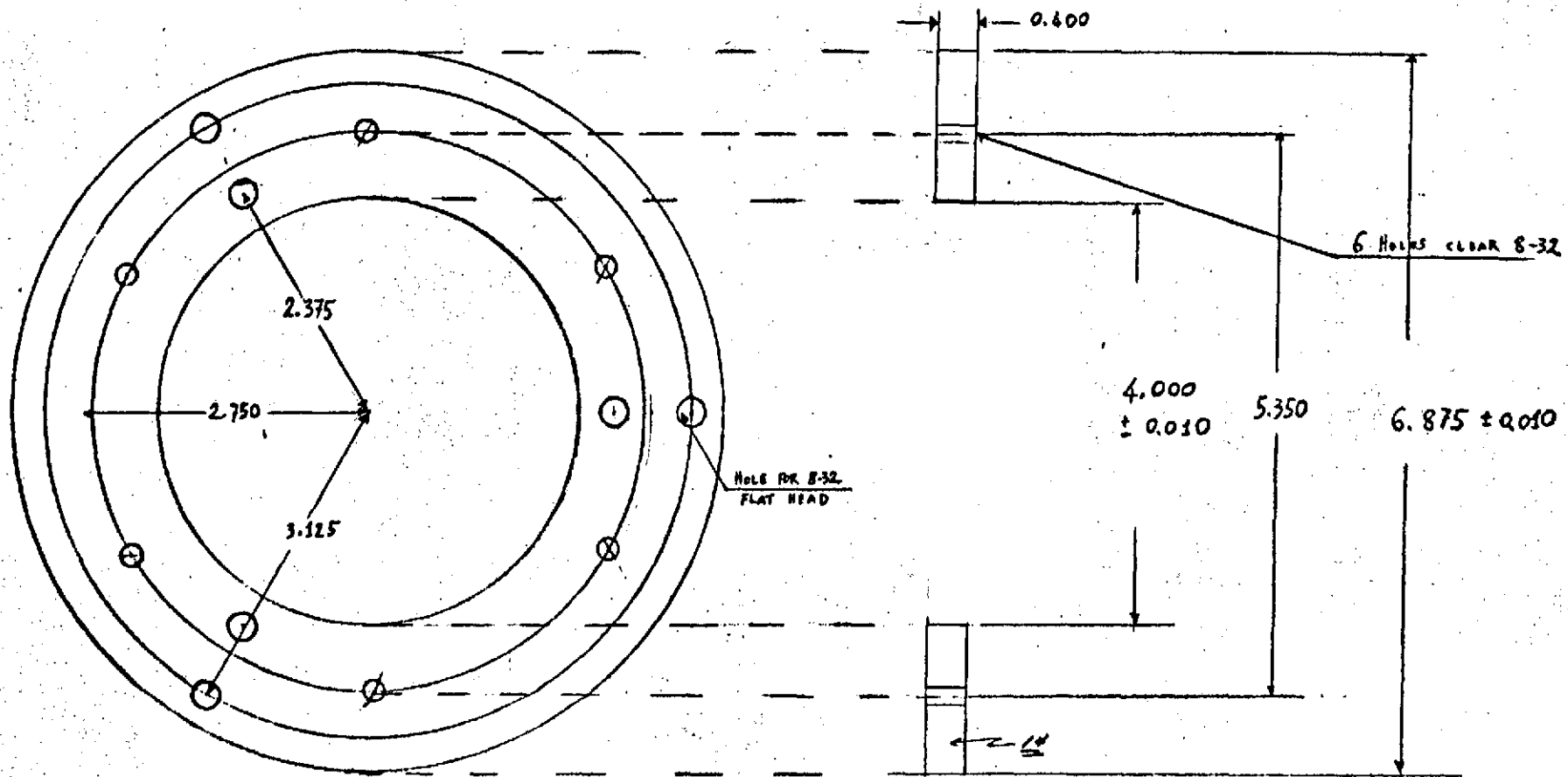
6 HOLES

CLEAR 8-32 ROUND HEAD

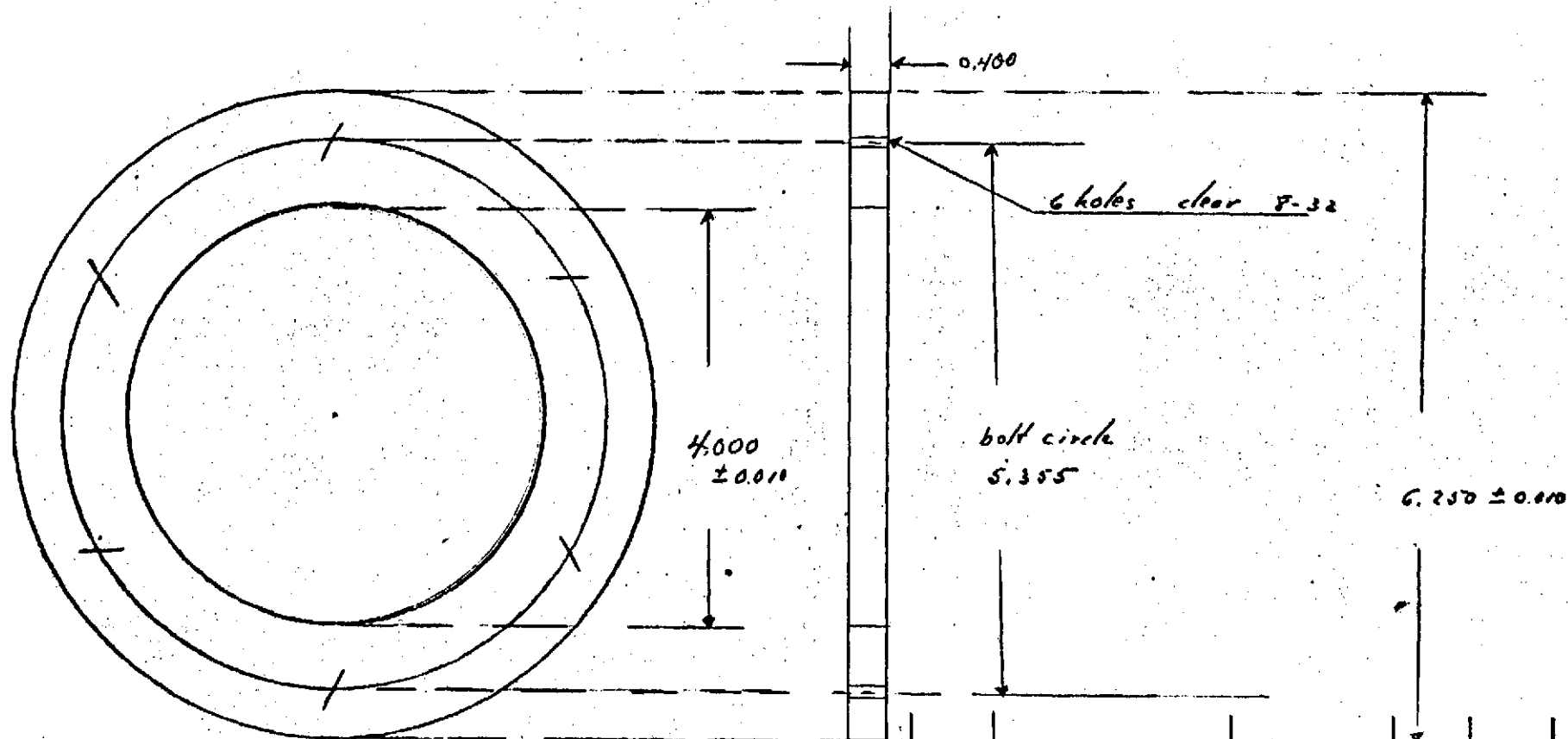
No 7	Description	Matériau	Précision	Spéc.	Quant.
Echelle 1:1	Matériau AL	6.13	—	LABORATOIRE D'ÉLECTRONIQUE QUANTIQUE	
Rb-M-1				Université Laval Québec 10 ^e	
Cavity bottom holder				Date 18/11/72	
				No 7	



No	Description	Matériau	Spéc.	Quant.
Echelle 1-1	Matériau as described	Précision —	LABORATOIRE D'ELECTRONIQUE QUANTIQUE Université Laval Québec 10 ^e	
Rb M-1 Fine tuning stud.			Date 17/11/72	No 11-12

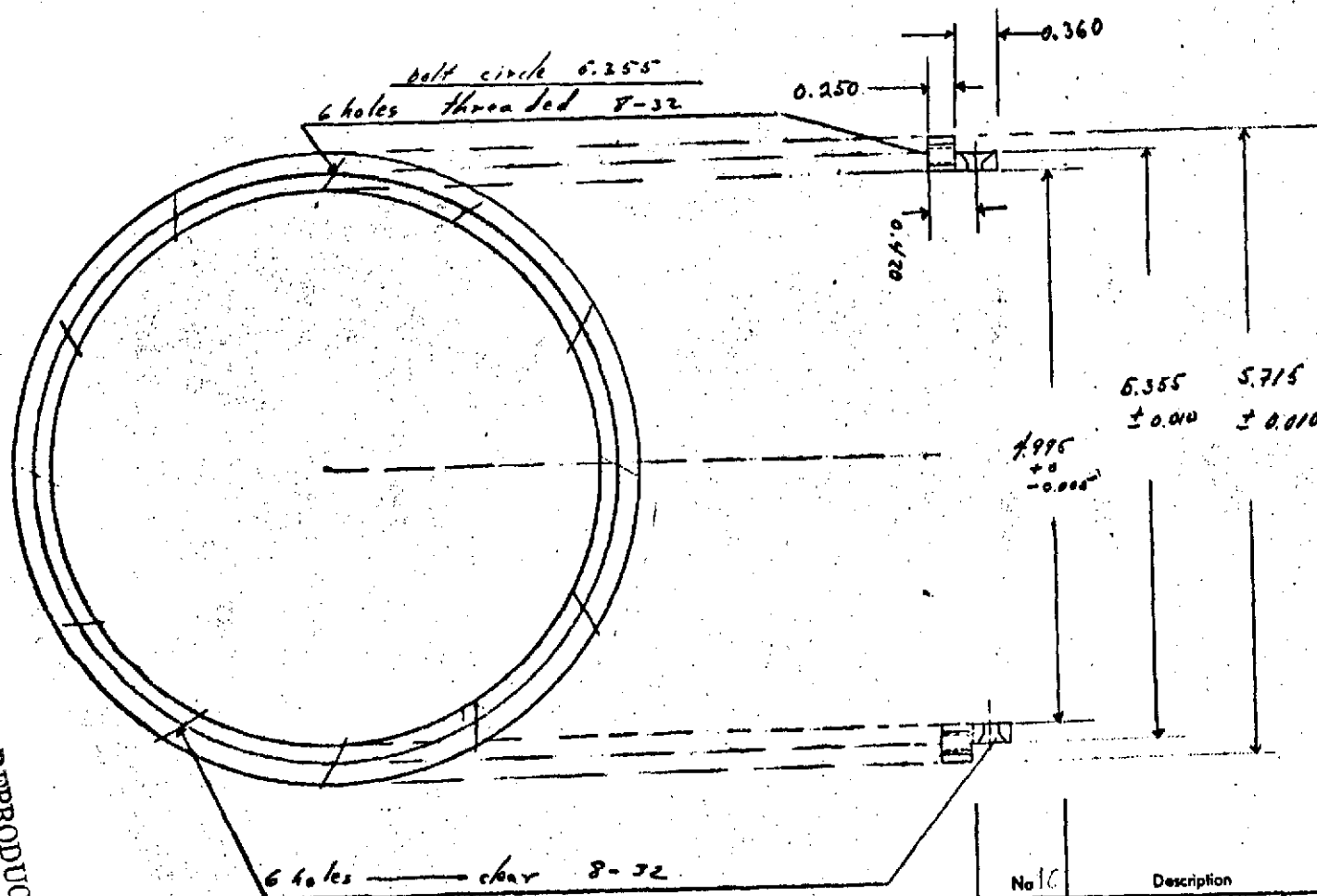


13				
14				
No	Description	Al plexiglass Matériau	Spéc.	Quant.
Échelle 1:1	Matériau G.B.	Précision -	LABORATOIRE D'ÉLECTRONIQUE QUANTIQUE Université Laval Québec 10 ^e	
R6H-1 shield spacer.			Date 14/11/72	No 15-1

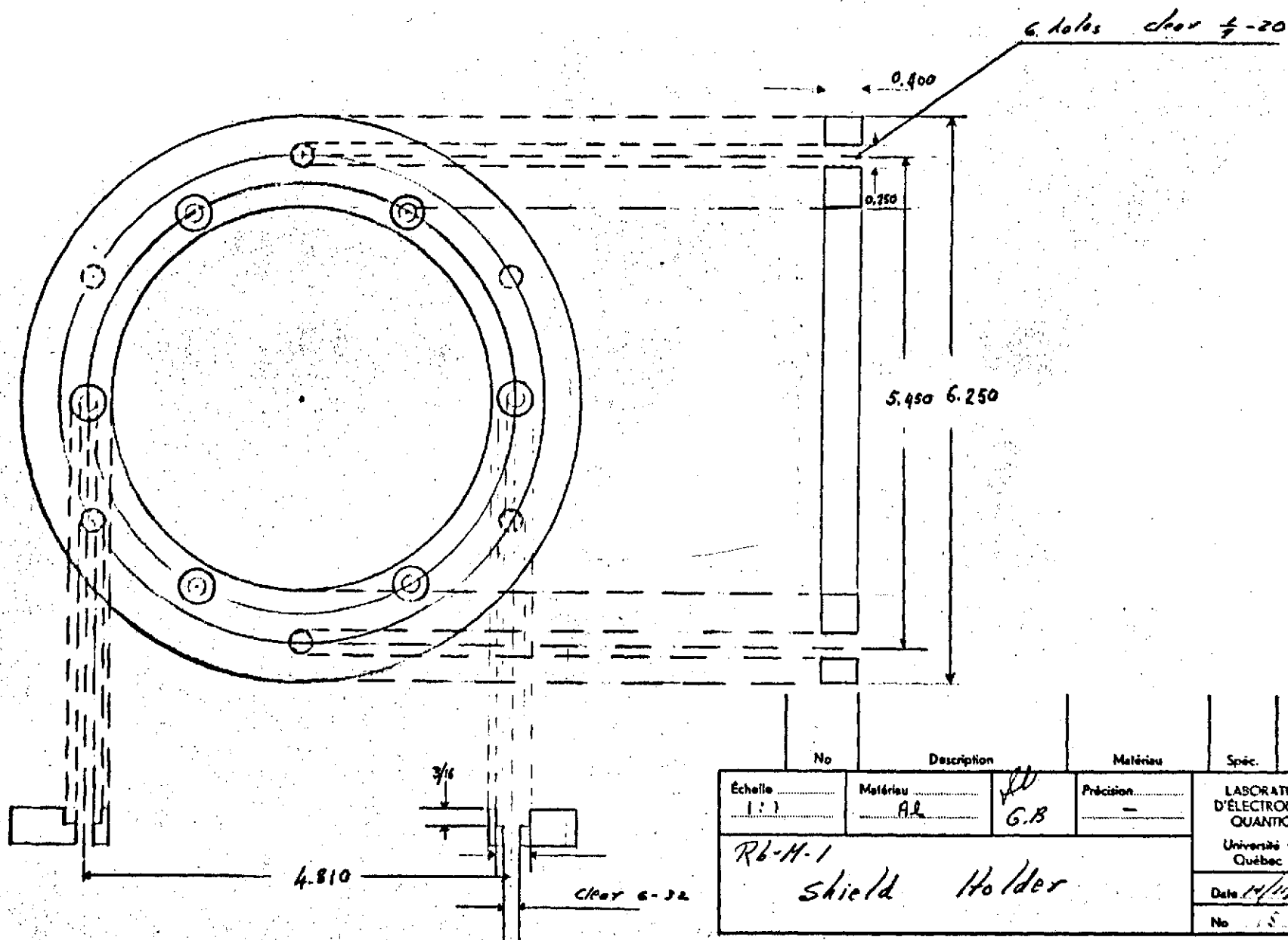


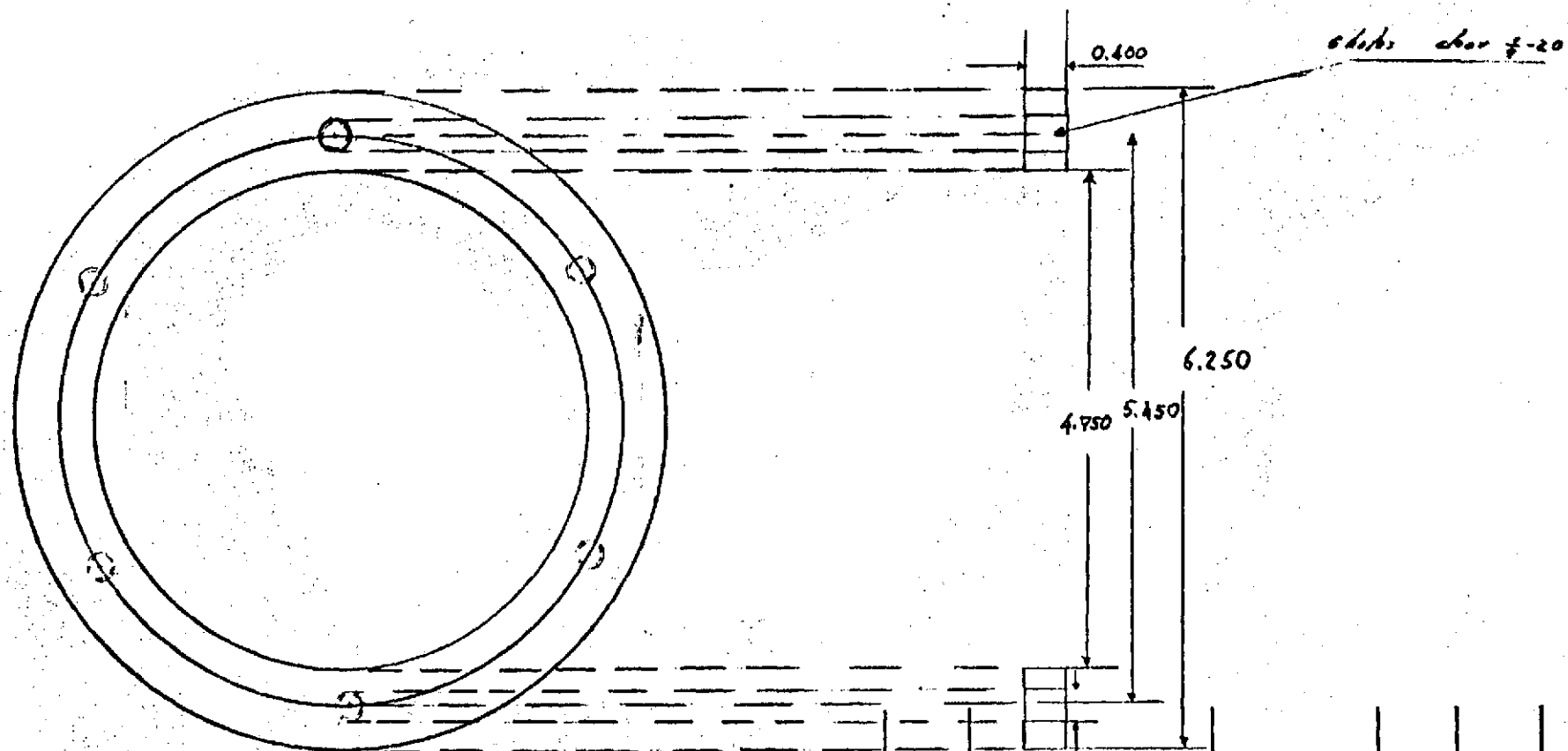
No	Description	Matériau	Spéc.	Quant.
15				
Échelle	Matériau	Précision	LABORATOIRE D'ÉLECTRONIQUE QUANTIQUE Université Laval Québec 10 ^e	
1:1	Al.	6.73		
Rb M-1 shield spacer			Date	
			No	15

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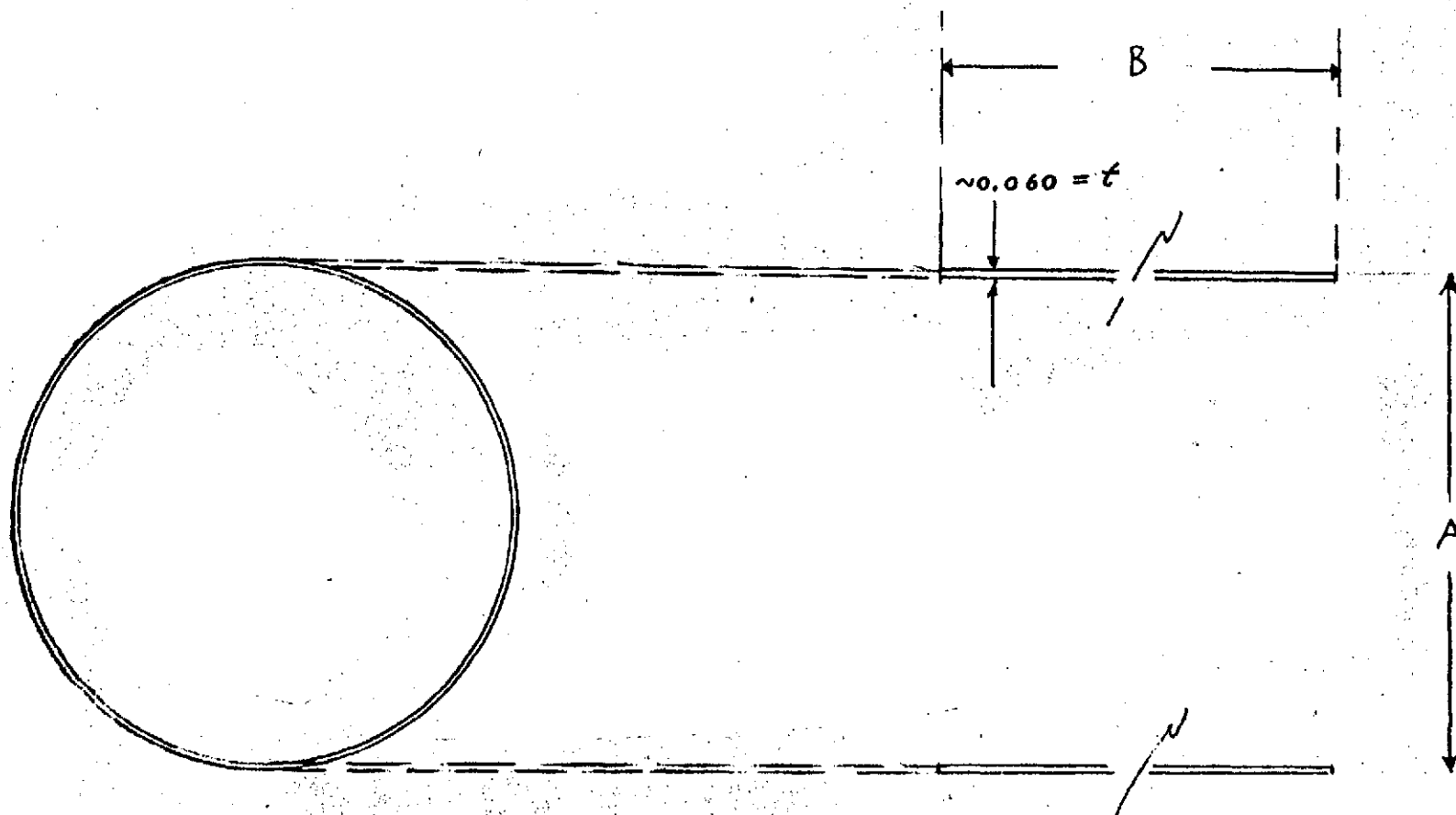


No	Description	Matériau	Spéc.	Quant.
Échelle 1:1	Matériau Al	Précision —	LABORATOIRE D'ÉLECTRONIQUE QUANTIQUE	
Rb-M-1			Université Laval Québec 10 ^e	
Main Cylinder Holder			Date 14/11/72	
			No 16	



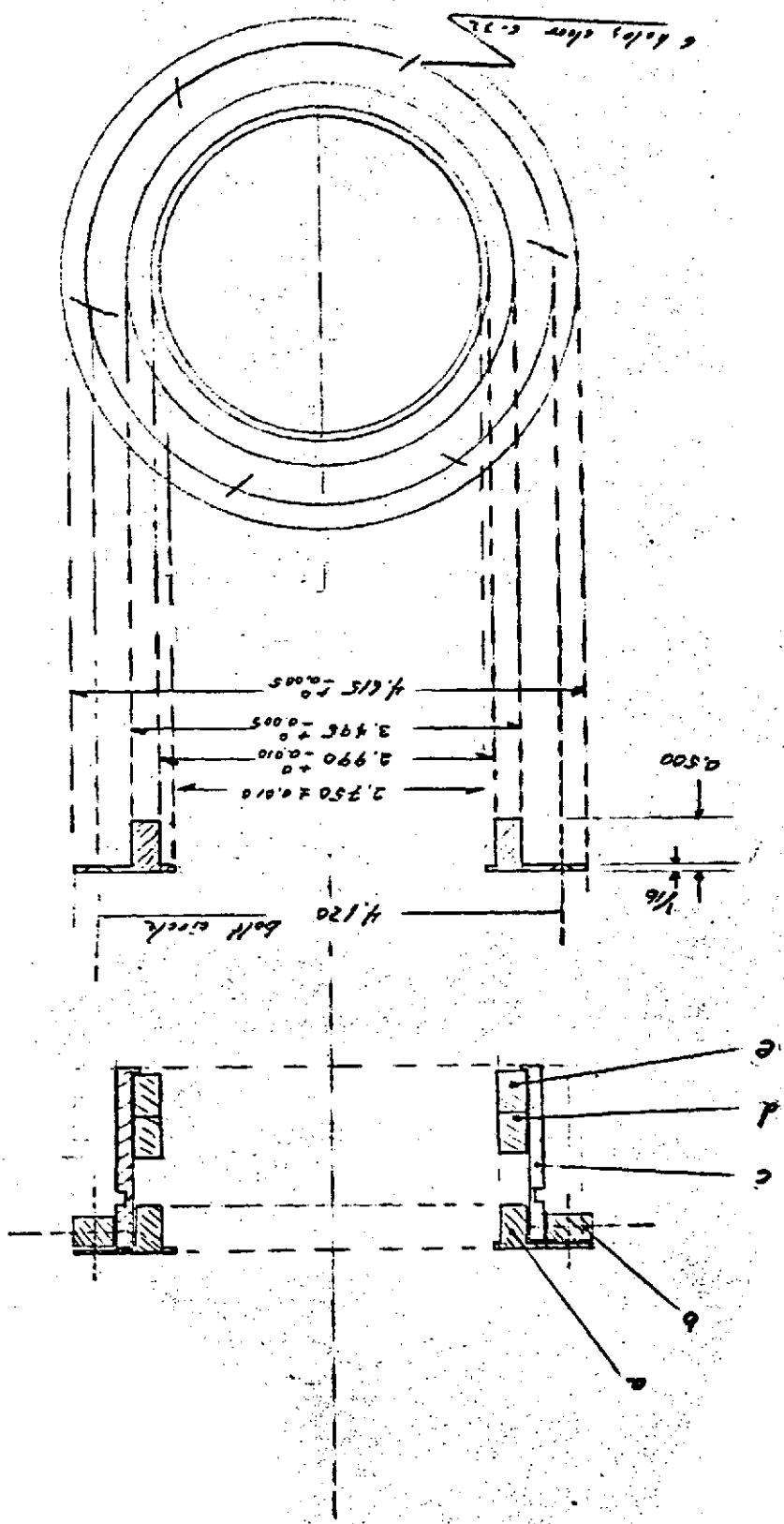


No	Description	Matériau	Spéc.	Quant.
	10.250			
Échelle	Matériau	Précision	LABORATOIRE D'ÉLECTRONIQUE QUANTIQUE Université Laval Québec 10 ^e	
1:1	Alu 505	6.75		
R6-H-1 Shield Holder				
			Date	14/11/72
			No	19

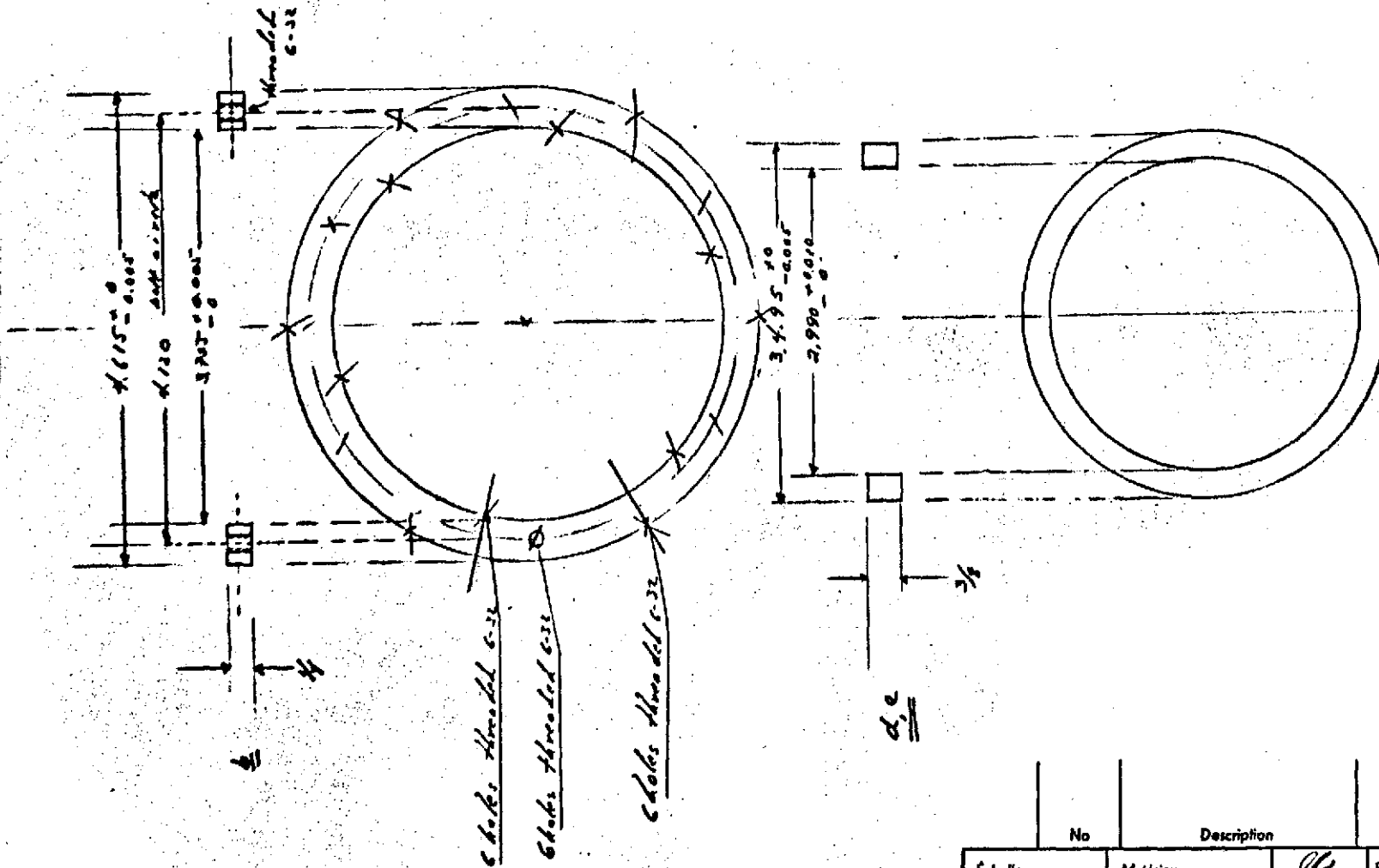


A	5.450	6.300
B	12.100	13.750

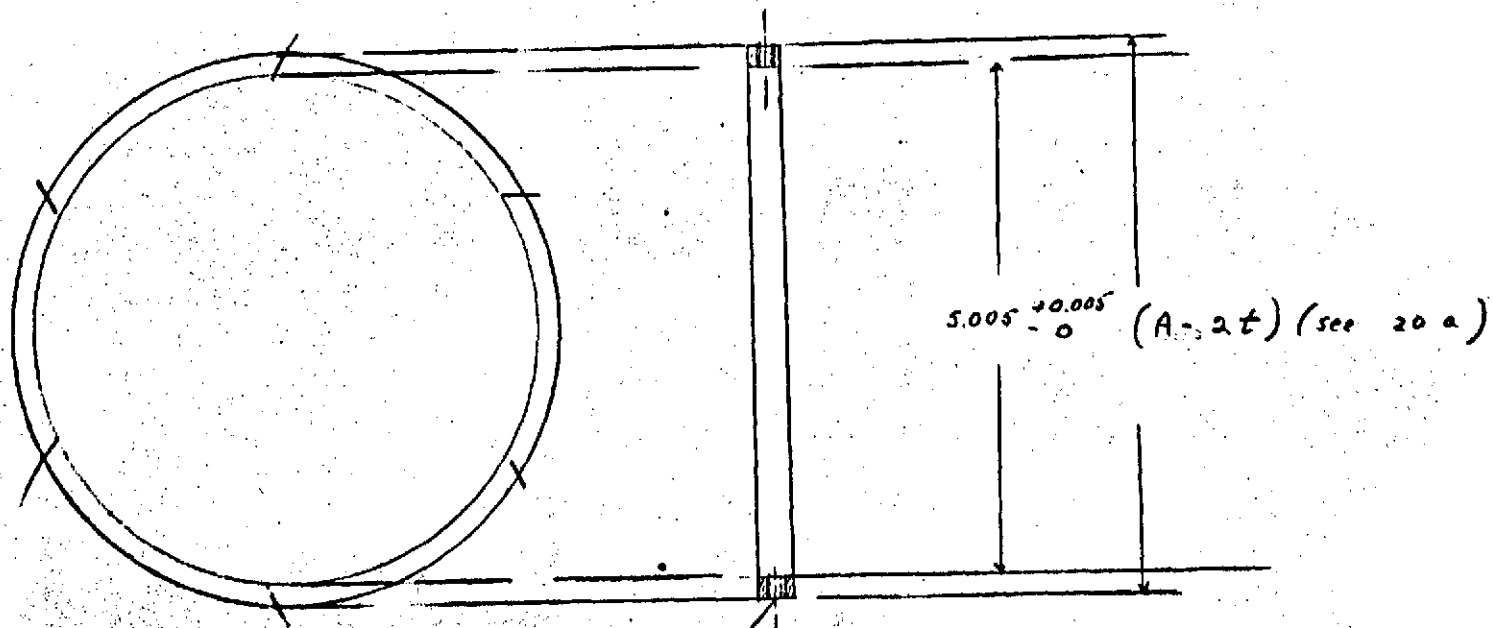
No	Description	Matériau	Spéc.	Quant.
Échelle 1:1	Matériau Al	Précision —	LABORATOIRE D'ELECTRONIQUE QUANTIQUE Université Laval Québec 12 ^e	
R6-H-1				
Softwood + Oven - cylindres				
			Date 14/1/72	
			No 302	



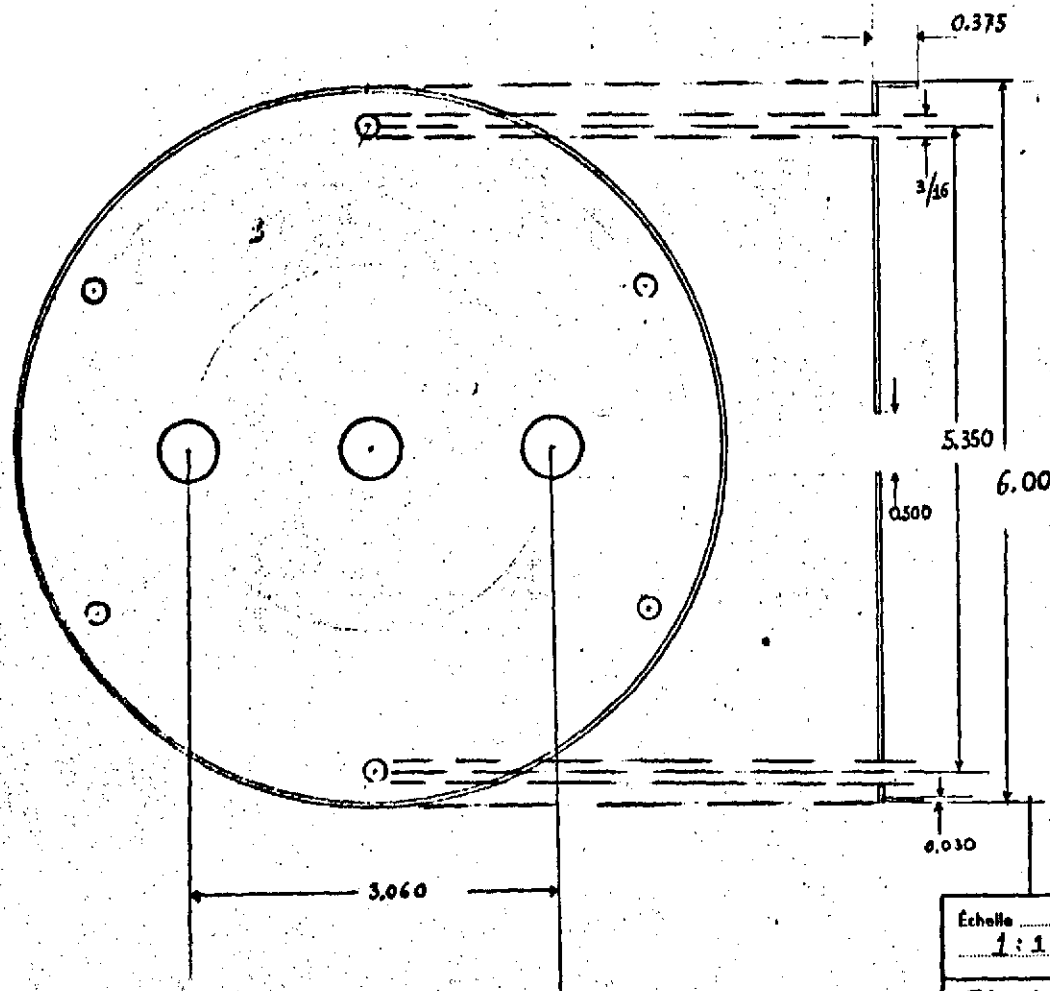
No	Description	Matériau	Spéc.	Quant.
Échelle 1:1	Matériau AL	Précision		
RbM 1	Filter Mount			
LABORATOIRE D'ÉLECTRONIQUE QUANTIQUE			Université Laval Québec 10 ^e	
Date 18/11/72			No 21, 210	



No	Description	Matériau	Spéc.	Quant.
Échelle 1:1	Matériau AL	PL G.B.	Précision —	LABORATOIRE D'ÉLECTRONIQUE QUANTIQUE
Rb-M-1 Filter mount part b, d, e.				Université Laval Québec 10°
				Date 14/1/12
				No 21, 6, 9, e.

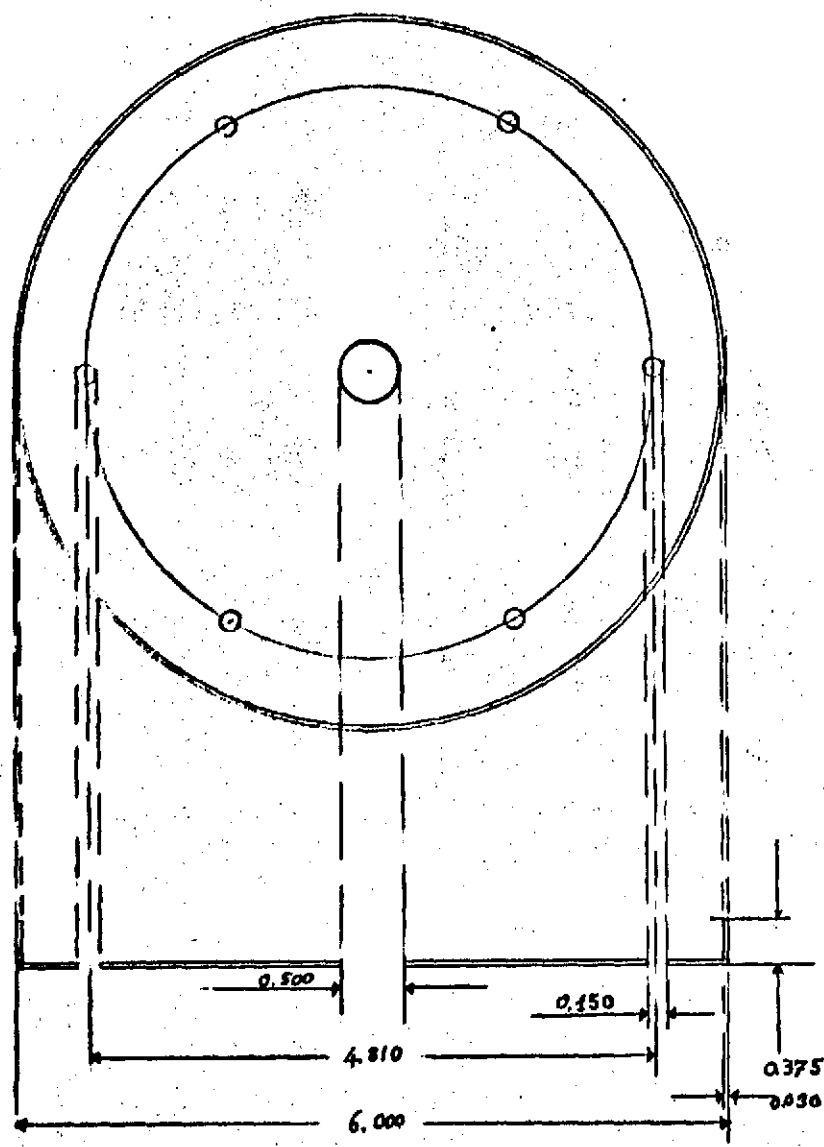


No	Description	Matériau	Spéc.	Quant.
Échelle 1:1	Matériau AL	G.B SU	Précision —	LABORATOIRE D'ELECTRONIQUE QUANTIQUE Université Laval Quebec 10 ^e
R6-H-1 Solenoid holder				Date 12/11/72 No 20 b

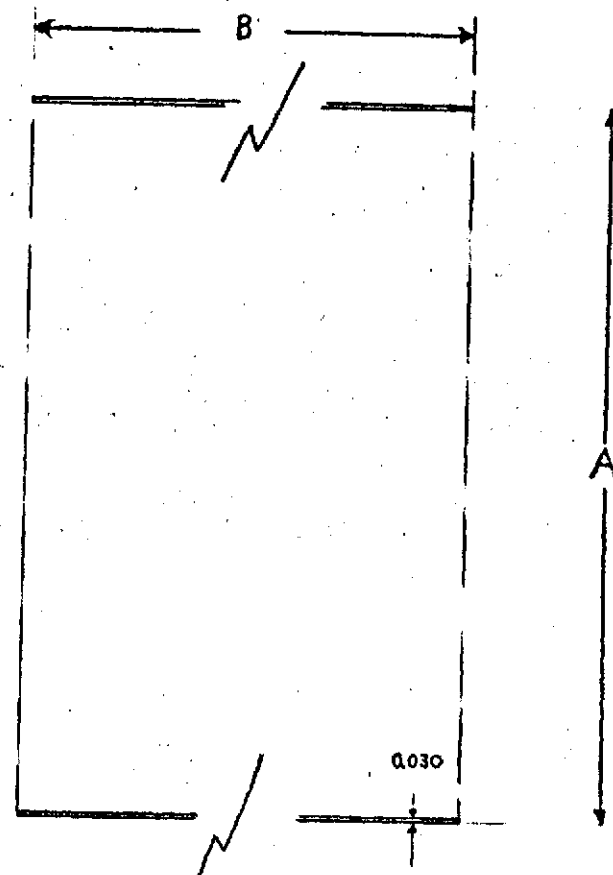
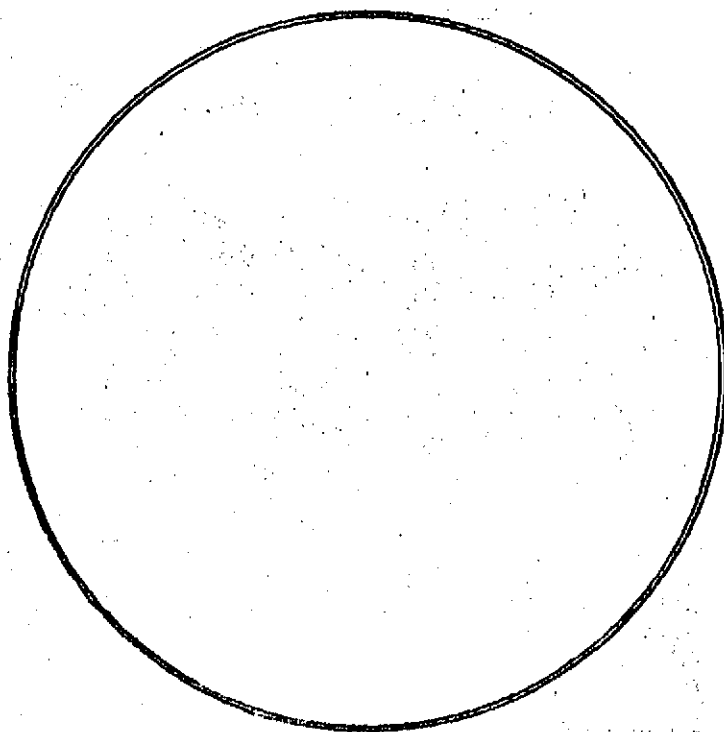


No	Description	Matériau	Spéc.	Quant.
R6-M-1	Shield Cap	6B.	—	—
Echelle 1:1 Matériau Moly Permalloy Précision —				LABORATOIRE D'ELECTRONIQUE QUANTIQUE Université Laval Québec 10 ^e Date 8/11/72 No S-1-CB

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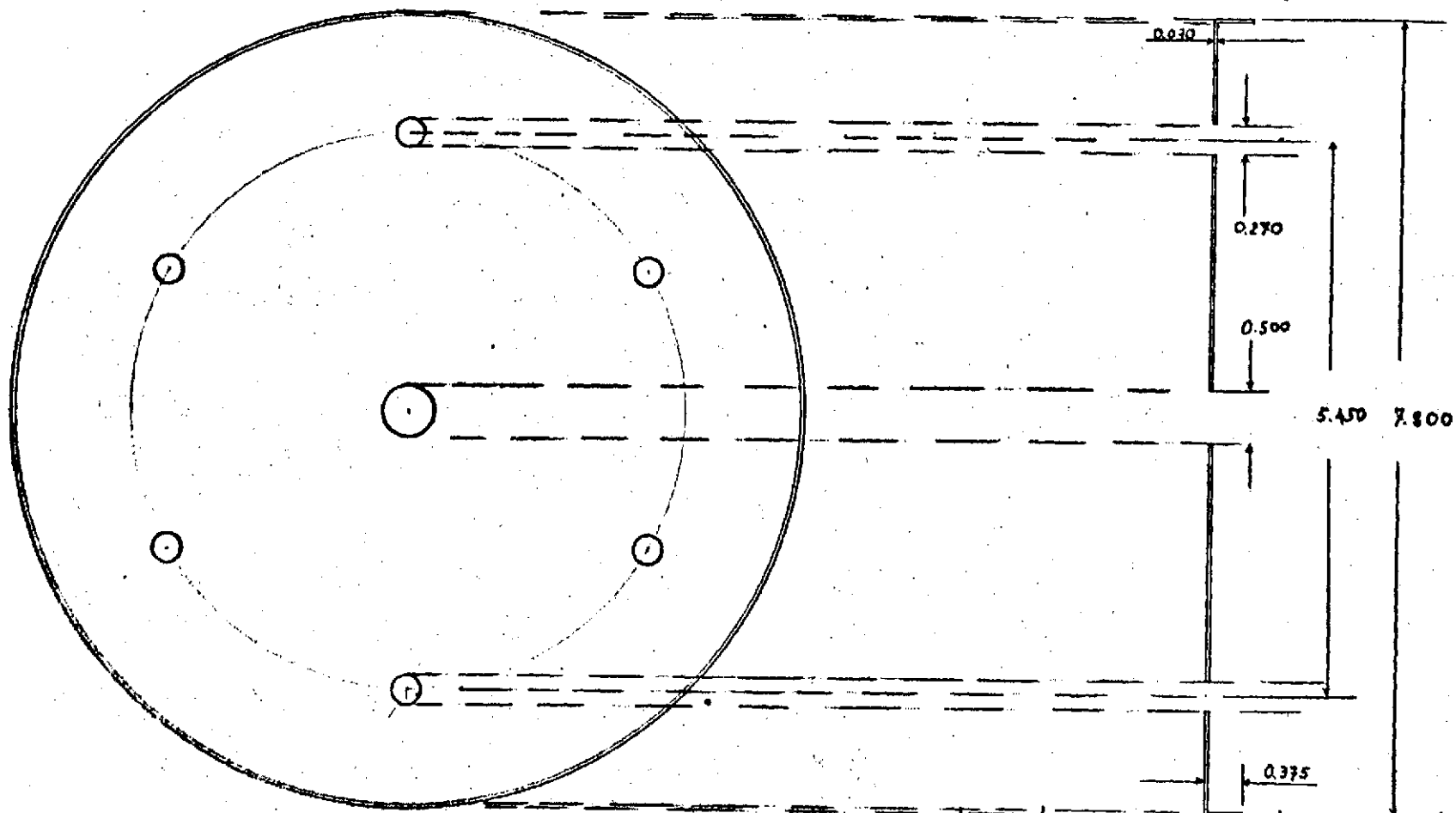


No	Description	Matériau	Spéc.	Quant.
Echelle 1:1	Matériau Haly-Permalloy	Précision GB	LABORATOIRE D'ELECTRONIQUE QUANTIQUE Université Laval Québec 10 ^e	
Rb-M-1 Shield Cap.			Date 8/11/72	No S-L-C-T



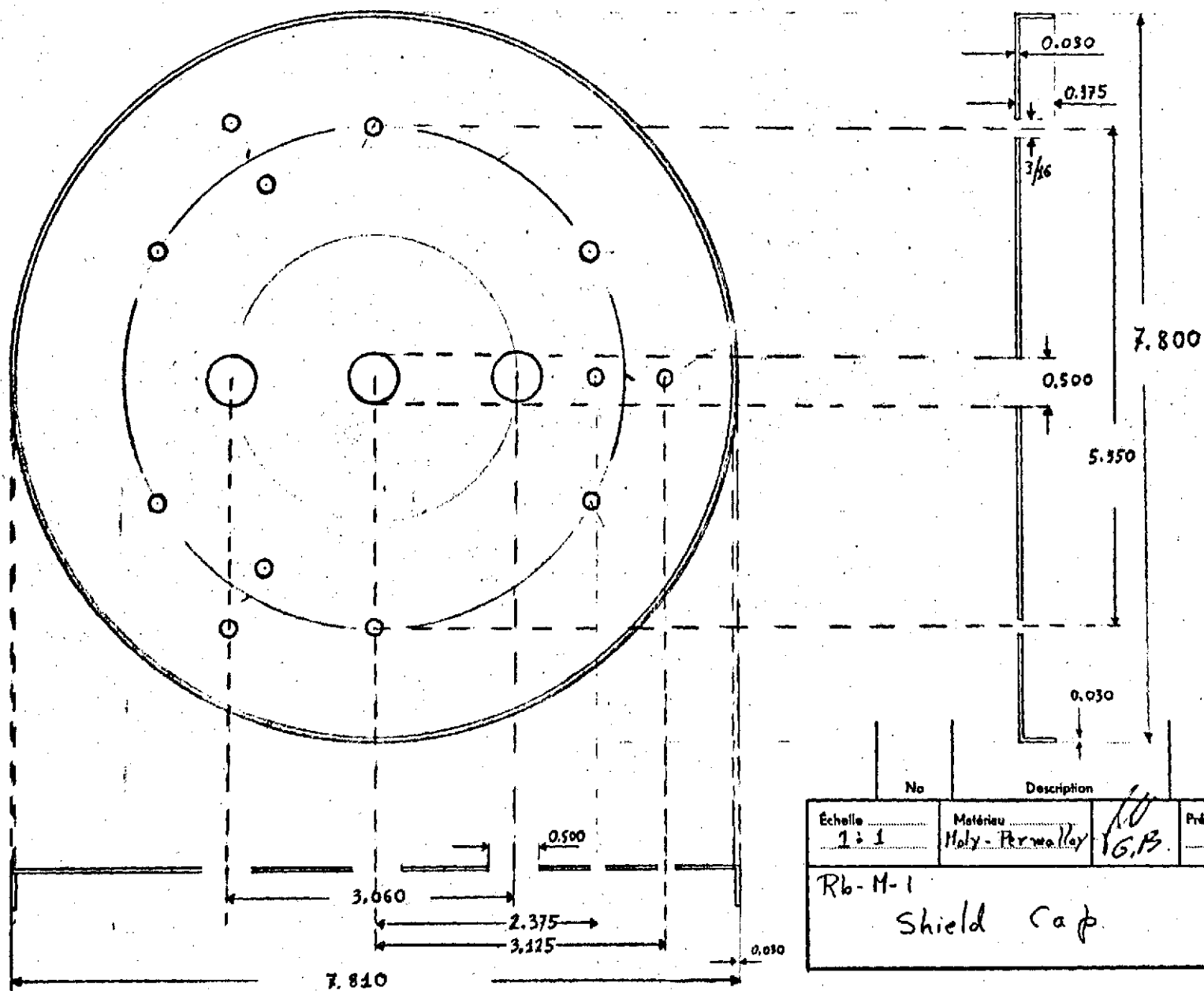
No	A	B	
S-3	7.740	14.790	must be compatible with caps - S-3-C-B and S-3-C-T
S-2	6.940	13.930	must be compatible with caps - S-2-C-B and S-2-C-T
S-1	5.940	13.070	must be compatible with caps - S-1-C-B and S-1-C-T

No	Description	Matériau	Spéc.	Quant.
Échelle 1-1	Matériau Mely-Permalloy	Précision 0.03	LABORATOIRE D'ELECTRONIQUE QUANTIQUE	
Rb-M-1 Shield Cylinder			Université Laval Quebec 10 ^e	
			Date 8/11/80	
			No S-1, 2, 3	



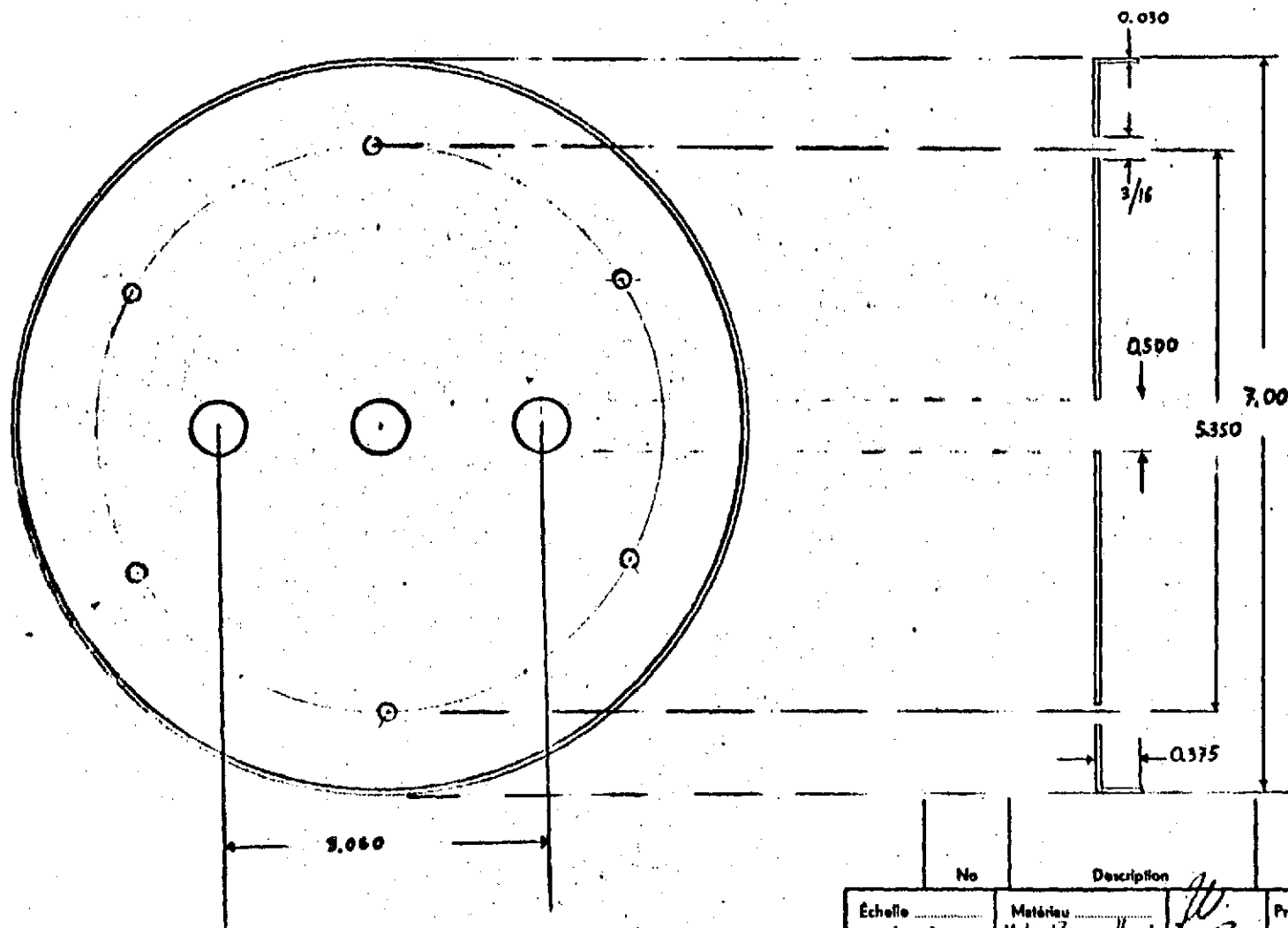
No	Description	Matériau	Spéc.	Quant.
R6-M-1	Shield Cap	Moly. Permalloy	LABORATOIRE D'ELECTRONIQUE QUANTIQUE	
			Université Laval Québec 10 ^e	
			Date 8/1/72	
			No 5-3-5-1	

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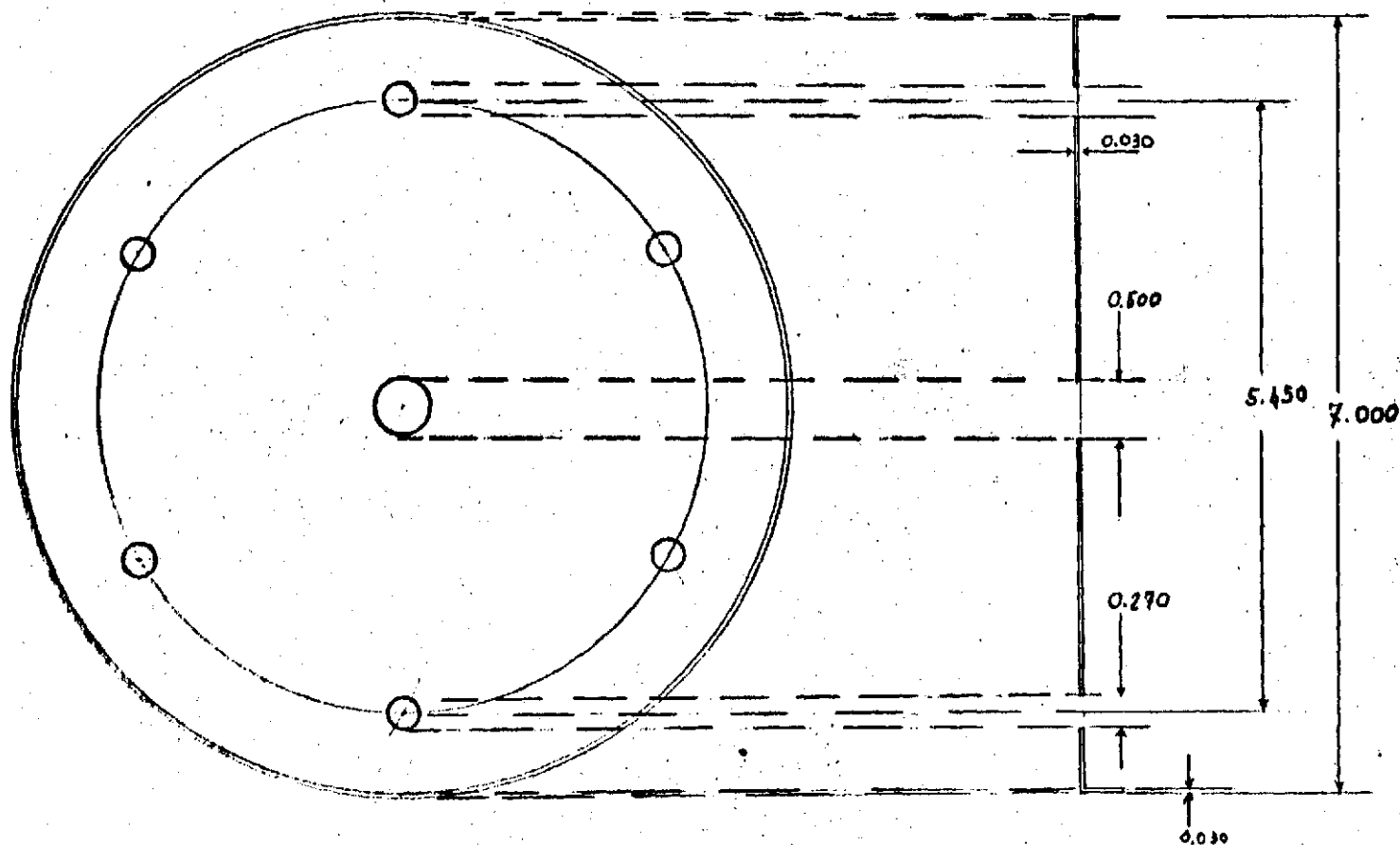


No	Description	Matériau	Spéc.	Quant.
Échelle 1 : 1	Matériau Moly - Permalloy	Précision 10 G.R.	LABORATOIRE D'ELECTRONIQUE QUANTIQUE	
Rb-M-1			Université Laval Québec 10 ^e	
Shield Cap			Date 8-11-72	
			No. S-3-C-13	

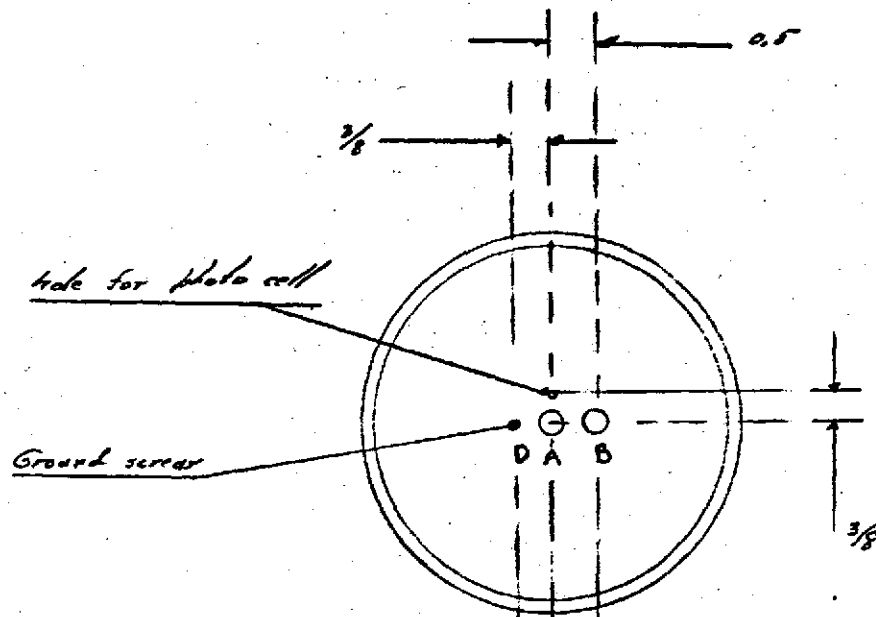
85



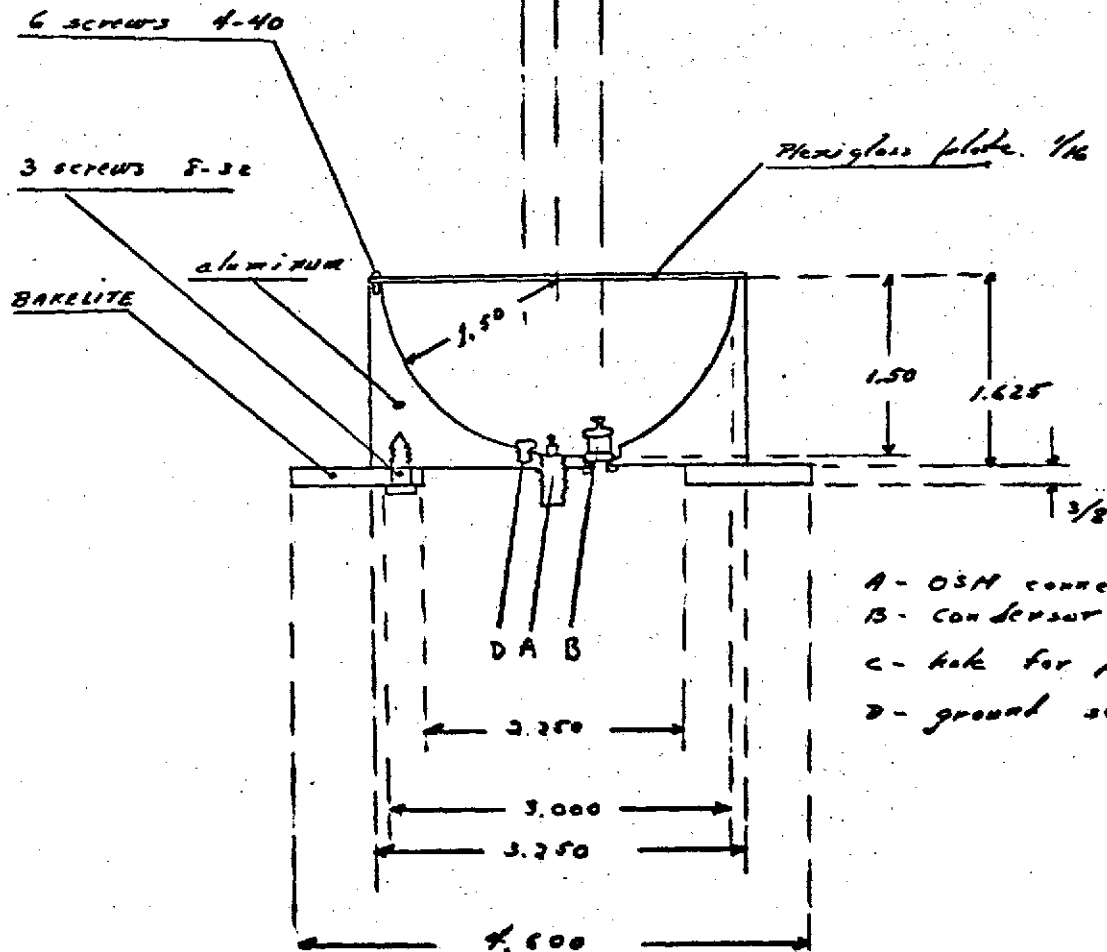
No	Description	Matériau	Spéc.	Quant.
Echelle 1:1	Matériau Ally Permalloy	Précision —	LABORATOIRE D'ELECTRONIQUE QUANTIQUE	
R6-M-1			Université Laval Québec 10 ^e	
Shield Cap.			Date 8/11/82	
			No 5-2-c-6	



No	Description	Matériau	Spéc.	Quant.
Echelle 1:1	Matériau Half Permalloy	Précision —	LABORATOIRE D'ELECTRONIQUE QUANTIQUE	
Rb H-1 Shield Cap.			Université Laval Québec 10 ^e	
			Date 8/11/72	
			No S-2-C-T	



No	Description	Matériau	Spéc.	Quant.
R6 H 1	lamp support & reflector	Précision	LABORATOIRE D'ÉLECTRONIQUE QUANTIQUE Université Laval Québec 10 ^e	
			Date 15.11.73	
			No 26	



- A - OSM connector
- B - Condenser (canon)
- C - hole for photo cell
- D - ground screw.